This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

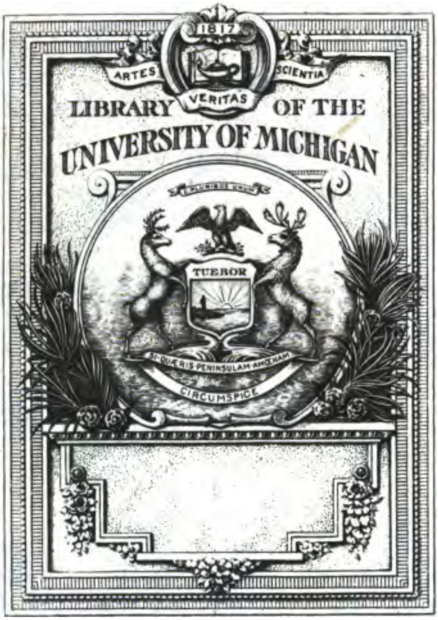
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

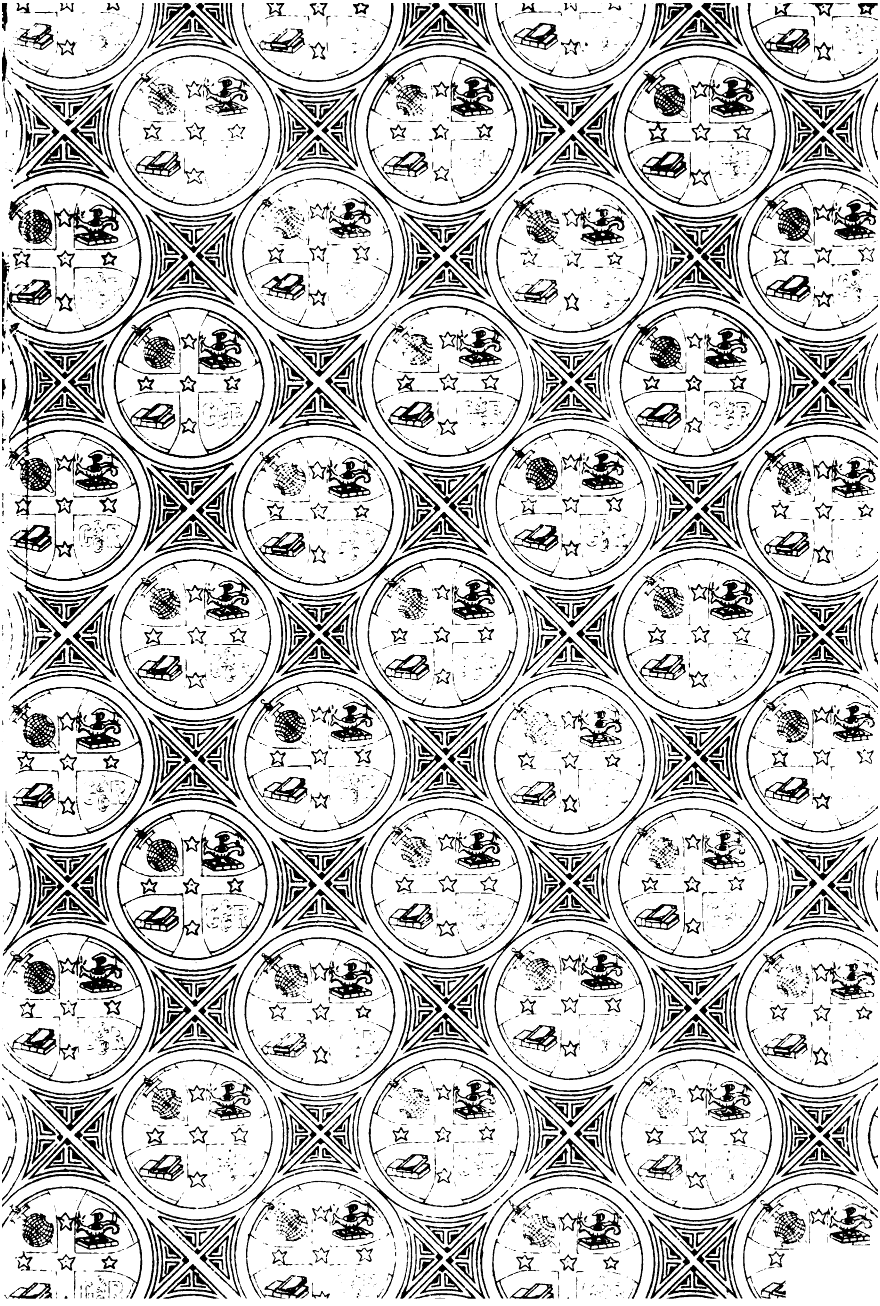
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`


1817
ARTES
SCIENTIA
VERITAS
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
E PLURIBUS UNUM
TUEBOR
SI QUÆRIS PENINSULAM AMŒNAM
CIRCUMSPICE



Chas. M. Spreit

MINERALOGY

AN INTRODUCTION TO THE STUDY

OF

MINERALOGY

FOR AUSTRALIAN READERS

erdinand

BY

F. M. KRAUSÉ, F.G.S., F.L.S.Lond.
LECTURER ON MINING IN THE UNIVERSITY OF MELBOURNE,
QUONDAM PROFESSOR OF MINERALOGY AND GEOLOGY
AT THE SCHOOL OF MINES, BALLARAT

GEORGE ROBERTSON & COMPANY
Melbourne, Sydney, Adelaide, Brisbane, and London

1896

Printed in England by
RICHARD CLAY & SONS, LIMITED,
LONDON & BUNGAY.

PREFACE

THIS volume, written at the earnest solicitation of many of my former pupils, as well as professional friends in different parts of Australia, has been in the first place designed as a text-book for the use of students at college, but I am led to hope that it may also find an auditory beyond the class-room. Its publication needs no apology from me. Assuredly in these Colonies, whose mineral resources have been so largely laid under contribution, it is fully recognized that the Science of Mineralogy has a distinct bearing on the material wants of the community. The difficulty so often experienced is to meet with an elementary book fit to serve both as a companion to the lectures and a guide to those who are debarred from attending a regular course of instruction. There is no lack of excellent works of this kind written by European and American authors, but they convey, as a rule, little or no information respecting the distribution and mode of occurrence of mineral species in Australasian localities. Seeing how important it is to encourage the scholar to verify by personal observation the truth of the teaching he has received, it becomes necessary, in order to foster this habit of observing in the young mineralogist, to make him acquainted with the places where he may study the natural occurrence of minerals, and whence he may draw the material for his laboratory practice. In the descriptive part of this book it has been my aim to present the subject essentially from the standpoint of an Australian inquirer.

It is now well understood that the study of rocks, so important to the geologist and mining engineer, can only be satisfactorily pursued by the aid of mineral, as distinguished from chemical, analysis; the optical properties, as revealed by microscopic examination, have accordingly received in the case of the rock-forming minerals rather more attention than is usually given in elementary text-books. Care has been taken to render the book of practical use in the laboratory, and the chemical properties and reactions leading to the identification of the species have been fully set out.

In my capacity as curator of the Ballarat Museum I have had occasion to analyze and determine mineral specimens from every part of Australasia, while in the course of my professional visits to the mining fields I have personally examined into the mode of occurrence of most of the minerals herein described. It would not, however, have been possible for me to specify all the mineral localities mentioned in these pages but for the information gleaned from the writings of Prof. Ulrich of Dunedin and Prof. Liversidge of Sydney, and the published lists given by Mr. H. Y. L. Brown, F.G.S., of Adelaide, the late Mr. E. B. Lindon, A.R.S.M., of Brisbane, and Mr. W. F. Petterd of Launceston.

F. M. K.

Melbourne, January 1896.

CONTENTS

PART I.—SYSTEMATIC MINERALOGY

CHAPTER I

INTRODUCTORY

CHAPTER II

CRYSTALLOGRAPHY: GENERAL MORPHOLOGY OF CRYSTALS

CHAPTER III

ISOMETRIC SYSTEM

CHAPTER IV

TETRAGONAL SYSTEM

CHAPTER V

RHOMBIC SYSTEM

CHAPTER VI

MONOCLINIC SYSTEM

CHAPTER VII

TRICLINIC SYSTEM

CHAPTER VIII

HEXAGONAL SYSTEM

CHAPTER IX

COMPOUND CRYSTALS

CHAPTER X

ABNORMAL FORMS OF CRYSTALLIZATION

CHAPTER XI

PHYSICAL PROPERTIES

CHAPTER XII

OPTICAL PROPERTIES

CHAPTER XIII

CHEMICAL PROPERTIES

CHAPTER XIV

DISTRIBUTION AND CLASSIFICATION

PART II.—DESCRIPTIVE MINERALOGY

PART I

SYSTEMATIC MINERALOGY

CHAPTER I

INTRODUCTORY

1. *Elements.* To our present knowledge there exist some sixty-eight substances which have so far resisted further analysis or decomposition. They are called *elements*, and are partly solid bodies (*e.g.* carbon, gold), partly fluids (*e.g.* bromine, mercury), and partly gaseous (*e.g.* oxygen, fluorine). Of these substances only a few, designated as *native elements*, have been found in an elementary condition in nature; the most of them occur in combination with one or more other elements. Gold, for example, is a native element, while quartz is a compound of silicon and oxygen.

2. *Minerals.* A *mineral* is a product of nature, has a fixed composition, and is without trace of organic structure, or to put it into the briefest language, a mineral is a *natural*, *homogeneous*, and *inorganic* body. Some substances formed by the art of man, such as glass, slag, alloys, and products of the chemical laboratory, often closely resemble minerals in respect to homogeneity and composition, and the processes of which they are the outcome suggest, no doubt, in many instances the probable origin of minerals of corresponding

composition. Beyond this, however, such artificial substances do not come within the province of the mineralogist, who, as has been stated, deals with matter in its natural condition. The true mineral is homogeneous, that is to say, the eye can detect in it no trace of composition, since the individual particles of which it is made up present a strict uniformity. This character distinguishes a chemical compound from a mechanical mixture, as well as an inorganic from an organic substance. An organized body consists of diverse parts (organs), the removal of any one of which would tend to destroy its existence or its identity. The circumstance of a natural body being in a liquid or gaseous state is not at variance with the recognized definition of a mineral. Such bodies, for example, as water, mercury, naphtha, carbonic acid, fire-damp, etc., possess all the properties demanded of a mineral, and these substances are accordingly considered genuine mineral species. Resin, on the contrary, though a natural and homogeneous substance, is, on account of its organic origin, of no concern to the mineralogist. Such substances as coal, amber, tripolite, pearl, struvite, etc., which are as a matter of expedience usually dealt with by the mineralogist, are not minerals in the proper acceptation of the term, since they are either transmuted organic matter or undeniably the result of organic agency.

3. *Rocks.* The bulk of the solid matter of the earth, as far as it has been laid bare to our observation, consists of material in which two or more minerals are *mechanically* combined. Such mechanical compounds are called *rocks.* In some rocks the component minerals are readily distinguished from each other, as the felspar, quartz, and mica in granite. In others the several constituents can be recognized only by the aid of a high magnifying power, as in the case of basalt, a rock which, though made up of felspar, augite, and magnetite, is to the unassisted eye scarcely distinguishable from a homogeneous body. The special

branch of inquiry which occupies itself with the mineral composition of rocks is termed *petrography*.

4. *Scope of Mineralogy.* It is the province of mineralogy to investigate the properties of simple, uncombined minerals, and in the pursuit of this investigation it avails itself largely of the aid of mathematics, physics, and chemistry. The successful study of mineralogy demands, therefore, a knowledge of the principles of these branches of learning. In order to fully recognize and describe the individual characters of mineral species inquiry should first be directed to the general characters of minerals and the general methods suitable for their determination, and the subject is accordingly divided into two parts, viz. *Systematic Mineralogy*, and *Descriptive Mineralogy*.

5. *Systematic Mineralogy.* The general properties of minerals are dependent on form, effects of light, composition, etc., and may be separately considered under the following heads—I. *Morphology:* Crystallization, isomorphism, heteromorphism, pseudomorphism, allotropy. II. *Internal structure* and *physical properties:* Crystalline structure, amorphism, cohesion, cleavage, fracture, hardness, tenacity, density, electricity, magnetism. III. *Optical properties:* Colour, streak, lustre, diaphaneity, refraction, diffraction, double refraction, polarization, pleochroism, iridescence, opalescence, asterism, phosphorescence, fluorescence. IV. *Chemical properties:* Taste, odour, feel, adhesion to the tongue, fusibility, volatility, solubility. V. *Distribution* and *paragenesis.* VI. *Classification.*

CRYSTALLOGRAPHY

CHAPTER II

GENERAL MORPHOLOGY OF CRYSTALS

6. *Crystals.* When mineral matter, or any other substance with a fixed chemical composition, passes from a gaseous or liquid to a solid state, its molecules arrange themselves in a more or less determinate order, and the mass itself is capable of assuming externally a regular geometrical form. Such a form is termed a *crystal*, and the branch of learning which occupies itself with the study of the mathematical and physical properties of crystals is called *crystallography*. A crystal is built up by successive layers or zones. Whether these layers of growth are deposited equally all round the nucleus (*origin*) of the crystal, or whether, as in Fig. 1, one side receive a larger extension than another, will depend on the site occupied by the crystal in relation to its surroundings, on the available supply of crystallizable matter, and other extraneous conditions. It is a mere accident, therefore, that permits the development of a crystal equably in all directions. But the nature of a crystal is in no way affected by such want of external regularity. Thus while the geometrician defines a cube as a space contained within six squares, the crystallographer comprehends by it any solid which is terminated by three pairs of planes normal to each other. The tabular crystals of pyrite so common in the Silurian slates and sandstones of our gold-fields illustrate this form of cubical crystallization. Similarly the faces of quartz crystals are rarely of equal size, some being abnormally large, others almost entirely suppressed; yet these apparently distorted crystals are in a crystallographic sense perfectly regular hexagonal prisms and pyramids. Thus in Fig. 1, which represents a transverse section of such a quartz

prism, the boundaries of the six-sided figure are all of different lengths; each of the angles, however, is that of the regular hexagon, viz. 120 degrees. We learn from this that it is the angles which determine the geometrical order of a crystal, while the size and shape of the faces are immaterial. The more minute the dimensions of a crystal, the more perfect, as a rule, are its geometrical proportions.

FIG. 1.

Crystals are bounded by plane geometrical surfaces, usually termed *faces*, the more common forms of which are the equilateral, isosceles, and scalene triangles, the square, rectangle, rhomb, rhomboid, deltoid, and hexagon. It is customary to restrict the use of the term *plane* to internal planes of a crystal, *e.g.* cleavage planes, plane of fracture, plane of symmetry. The intersection of two faces produces an *edge*. In pyramids the edges around the base are called *lateral* edges, those which meet at the apex *polar* edges. In prisms the edges which bound the top and bottom planes are called *basal* edges, while the parallel edges formed by the side faces are the *vertical* edges. The meeting of two edges forms a *plain angle*; the dihedral angle between two faces is an *interfacial* angle; the intersection of three or more faces gives rise to a *solid angle*.

The angles between similar faces of a crystal are constant in the same mineral species, irrespective of the introduction of new, or the suppression of intermediate faces. Thus a mineral may assume both the forms represented by the subjoined diagrams (Figs. 2 and 3). In the first crystal let

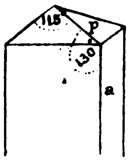


FIG. 2.

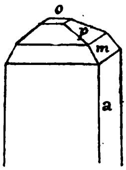


FIG 3.

the angle between the prismal face *a* and the pyramidal face *p* be 130°, and that at the apex of the pyramid 115°. In the second crystal the faces *p* and *a* are separated by the new faces *m* and *o*; when produced, however, they intersect at an angle of 115°. Likewise, if two faces of the truncated pyramid be produced in an upward direction they will meet at an angle of 130°.

7. *Symmetry.* A polygon which is capable of being divided in such a way that the two parts are exactly alike and in exactly the same position in regard to the dividing line is called a *symmetrical figure,* and the dividing line a *line of symmetry.* Thus any rectilinear figure held against a mirror would together with its image form a symmetrical figure, while the mirror constitutes a *plane* of symmetry. In Fig. 4 we have a symmetrical figure divided by a line of symmetry *x y*. Not only are the parts A and B alike, but the adjoining angles on opposite sides of the line of symmetry are equal. On the other hand, the form represented by Fig. 5 is an *asymmetrical* figure, since although the two segments C and D are equal, the angles on opposite sides of the dividing line are in reversed positions.

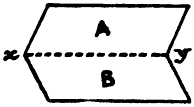


FIG. 4.

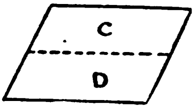


FIG. 5.

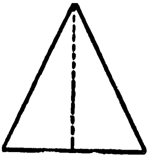


FIG. 6.

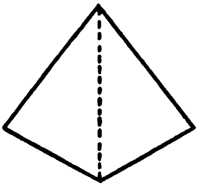


FIG. 7.

The number of lines of symmetry varies in different figures. In the isosceles triangle (Fig. 6) there is but one line of symmetry, viz. the perpendicular drawn from the apex to the base. The trapezoid (Fig. 7) likewise has but a single line of symmetry, viz. the diagonal which divides the figure into two equal scalene triangles. (The other diagonal divides it into two unequal isosceles triangles.) In the rhomb (Fig. 8) there are two lines of symmetry, viz. the diagonals, which are of unequal length and bisect under right angles. In the rectangle (Fig. 9) there are also two lines of symmetry, viz. the diameters, of different length and bisecting each other under right angles. In the isosceles triangle (Fig. 10) there are three lines of symmetry, all of equal length, viz. the perpendiculars from the angles to the centres of opposite sides. The square (Fig. 11) is symmetrical about four lines, viz. the two diagonals and the two diameters.

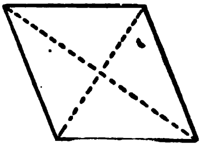


FIG. 8.

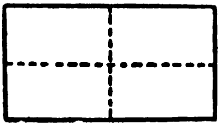


FIG. 9.

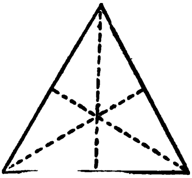


FIG. 10.

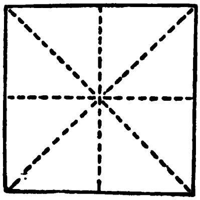


FIG. 11.

Similar symmetrical relations obtain in solids. The cube is symmetrical about nine planes, viz. three parallel to the faces, and six diagonally across the crystal (see Fig. 16). In the hexagonal prism there are seven planes of symmetry, viz. six vertical, placed 60° apart, and one horizontal. In the square prism there are five planes of symmetry, viz. four vertical, placed 45° apart, and one horizontal. In the rhombic prism there are three, viz. two vertical, placed under right angles to each other, and one horizontal. In the oblique prism there is but one plane of symmetry; it is vertical, and lies in the direction of the obliquity. The line of intersection of two or more planes of symmetry is termed an *axis of symmetry.*

8. *Zones.* If the edges of three or more faces of a crystal are parallel, then the planes lying within the space of these crystal faces constitute a *zone;* and assuming the several planes of a zone to pass through one point, then the line of intersection of these planes is the *zone axis.* Thus the vertical faces of a cube or polygonal prism enclose a zone; the central axis of such a crystal being parallel to the vertical edges constitutes a zone axis. Any plane parallel to the basal planes is called a *zone plane,* which is right-angled to the zone axis.

9. *Crystal axes.* The position of a plane is fixed by any three points, such as the terminating points of three lines. Lines of indefinite length drawn within the body of the crystal with the object of determining the relation of the crystal faces are called *crystal axes.* Crystal axes are always axes of symmetry. The point of intersection of the axes marks the *origin* of the crystal around which, and in the direction of the axes, the molecular growth has taken place. The distances, measured along the axes, from the origin to the face of a crystal are the parameters. Thus in Fig. 12 the position of the plane *a b c* is determined by the ratio of the parameters *o a*, *o b*, and *o c*; in other words, a face is *referred* to the axes, the relative length of which is known.

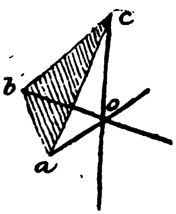


Fig. 12.

10. *Rationality.* In Fig. 13 the plane M is referable to the axes *a*, *b*, and *c*, one of which may be considered = 1.

To fix the position of a second plane N, which is not parallel to M, we require to know the ratios of the distances $\frac{oh}{oa}, \frac{ok}{ob}, \frac{ol}{oc}$. These ratios, briefly expressed by h, k, l, are called the *indices* of the plane N. The indices, together with the length of the axes, determine the position of a plane. In natural crystals these indices always represent simple numbers, such as 0, 1, 2, 3, 4, 5, rarely exceeding 6, while irrational numbers, such as $\sqrt{2}$, $\sqrt{5}$, do not occur. The symmetry of natural crystals is accordingly of a simple order, viz. twofold, fourfold, threefold, and sixfold, while regular geometrical forms of a type higher than the octahedron or cube are unknown. Thus the regular octagon and dodecagon, involving as they do irrational values of 2·414 and 1·366 respectively, are crystallographically impossible; similarly the regular dodecahedron, which conditions pentagonal symmetry, the regular eight-sided and twelve-sided prisms and pyramids, have no existence as natural crystals.

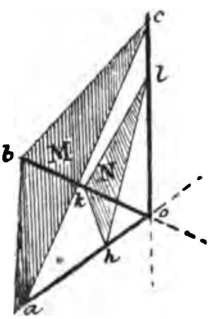


FIG. 13.

11. *Crystallographic systems.* We have seen that the number of planes of symmetry and the angles at which these planes intersect vary in different crystals. There are six kinds of symmetry possible, and by grouping together those forms which possess an equal degree of symmetry, *i.e.* in which the relations of the planes of symmetry are analogous, we establish six *crystallographic systems*, viz.—

(1) The *Isometric* (monometric or cubical) *System*, in which three axes of equal length intersect under right angles. Each axis is a principal axis.

(2) The *Tetragonal* (dimetric) *System* has three axes right-angled to each other; two of equal length, called

the *lateral* axes, and the third, or *principal* axis, either longer or shorter than the other two.

(3) The *Rhombic* (orthorhombic, or trimetric) *System*, having three axes perpendicular to each other, all of unequal length. There is no principal axis, and for descriptive purposes any one may be selected as such. The larger of the lateral axes is termed the macrodiagonal, the shorter the brachydiagonal axis.

(4) The *Monoclinic* (Oblique, or Clinorhombic) *System* has three axes of unequal length, two right-angled, the other oblique. Crystallographically there is no principal axis, but geometrically it is usual to select as vertical axis one of the two which intersect each other obliquely. The lateral axes are then right-angled; and the chief axis stands normal to one lateral axis, called the *orthodiagonal*, and oblique to the other, called the *clinodiagonal* axis. There is but a single plane of symmetry, viz. the clinodiagonal section, which passes through the vertical and clinodiagonal axes. In "reading" a crystal of this system we place the chief axis vertical and look along the plane of symmetry (see Fig. 14). The orthodiagonal *b* (which is also the axis of symmetry) will then be a transverse horizontal line, and the clinodiagonal *a* a line inclining from back to front. The chief factor required is the angle β, which is less than a right angle.

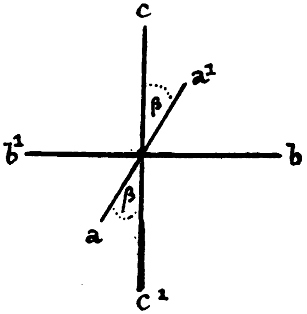


Fig. 14.

(5) The *Triclinic* (Anorthic or Asymmetric) *System* has three axes of different length, and all inclined to each other. There is no plane of symmetry, and no principal axis. Any one of the axes may be taken as the vertical,

when the remaining two become the macrodiagonal and brachydiagonal axes respectively.

(6) The *Hexagonal* (Rhombohedral) *System* has four axes. The three lateral axes are of equal length, lie in one plane, and are placed 60° apart; the principal axis is normal to the others, and is either longer or shorter than the lateral axes.

12. *Notation.* To ensure precision as well as terseness in description, crystallographers make use of symbols to indicate the position of the several faces of a crystal in relation to its axes. There are several methods employed, the most conventional being those originally made known by Naumann, Weiss, and Miller respectively.

Naumann's method of notation. In the isometric system the octahedral face is distinguished by the letter O, and since all the faces are alike, this sign stands also for the complete crystal. In the other crystallographic systems the fundamental pyramid has the sign P; the orthodiagonal and clinodiagonal planes in monoclinic crystals being further distinguished by a straight or slanting bar across the letter, thus *P̶* and *P̸* respectively. Derivative faces are indicated by the coefficients m and n, where m is either > 1 or < 1, and refers to the vertical axis, and $n > 1$ refers to the longer lateral axis. The sign ∞, denoting infinity, implies that a face is parallel to a particular axis. The basal planes, or planes parallel with the base of all prisms, are indicated by the symbol OP. The rhombohedron, or any of its faces, is distinguished by the letter R.

In *Weiss's* notation the three parameters are indicated by the letters a, b, and c. The complete symbol $a : b : c$ applies to crystals with unequal axes, viz. those belonging to the rhombic, monoclinic, and triclinic systems. The letter b refers to the macrodiagonal and orthodiagonal axes, the letter c to the principal axis. The symbol $a : a : c$ applies to the tetragonal system, $a : a : a : c$ to the hexagonal, and $a : a : a$ to the isometric system. To describe a face other than a unit plane the coefficients m and n are used, as in Naumann's method of notation, the general formula being $a : nb : mc$. Numerically expressed, the shortest parameter is taken as = 1, the others are multiples or sub-multiples such as 0, $\frac{1}{2}$, 1, $\frac{3}{2}$, 6, and ∞. Assuming, for example, that the triangular plane N in Fig. 7 intercepts the axis a at a distance $oh = \frac{1}{3}$, the axis b at a distance $ok = \frac{4}{9}$, and the axis c at a distance $ol = \frac{2}{3}$. The plane has the general symbol $a : nb : mc$, its parameter ratios are $\frac{1}{3} : \frac{4}{9} : \frac{2}{3}$, and these may be reduced to $1 : \frac{4}{3} : 2$, which is accordingly its appropriate symbol.

Miller's notation. Here the unit lengths of the axes are h, k, and l, and the indices represent the fractions of a unit at which a face cuts the axes. Thus in the example given in connection with Fig. 7, if $oh = h$, $ok = k$, and $ol = l$, then we may substitute for Weiss's figures $1 : \frac{4}{3} : 2$ their equivalents $\frac{1}{4} : \frac{1}{3} : \frac{1}{2}$, without altering the ratio of the axes. In practice only the denominators are used, hence the complete symbol for the face N is 4 3 2.

Parallelism is indicated under Miller's system by the cipher 0. Thus Weiss's symbol $\infty a : ml : nc$ is rendered by Miller into $0\ k\ l$; and Weiss's $\infty a : l : \infty c$ becomes Miller's 0 1 0.

For the hexagonal system Miller uses three axes instead of four. The three axes are all inclined, as in the triclinic system, but they are of equal length, and run parallel to the planes of the unit rhombohedron, and normal to alternate faces of the hexagonal pyramid.

The notation in *Dana's* "System of Mineralogy" is a modification of Naumann's method. In the isometric system the face of the cube is marked by 0 (cipher), that of the octahedron by 1. In the tetragonal system the principal axis is a, the two lateral axes b. Pyramid faces with longer or shorter vertical axes are described by coefficients as in Weiss's system, viz. $2a$, $\frac{3}{2}a$, $3a$, etc., and $\frac{3}{4}a$, $\frac{1}{2}a$, $\frac{1}{3}a$, etc. Faces parallel with an axis are indicated by the letter *i* (infinite). The cipher o stands for the basal plane of all prisms, to whatever crystallographic system they belong. In the rhombic system *a* is the vertical axis, *b* the brachydiagonal, *c* the macrodiagonal axis. In the rectangular prism a plane parallel with the vertical and macrodiagonal axis receives the sign *i–ī*; if parallel with the vertical and brachydiagonal the sign *i–ĭ*. In the rhombic prism the corresponding planes are marked by *I* (capital letter). In the monoclinic system *a* is the vertical, *b* the clinodiagonal, and *c* the orthodiagonal axis. The oblique angle *a* over *b* is denoted by $\wedge$ *C*. The sign of parallelism is the letter *i*, as in the rhombic system; planes which are parallel to the clinodiagonal axis are further distinguished by an oblique dash, thus *ì*. Finally, in the hexagonal system *a* is the sign for the vertical axis, *b* that for each of the lateral axes.

In every crystal which has a plane of symmetry there are at least two faces equal, parallel, and occupying analogous positions in respect to the axes. In some cases the whole of the faces are the counterpart of a single plane, that is to say, all are crystallographically identical, and therefore entitled to the same notation. But in order to distinguish the individual faces it is customary to resort to the use of the positive and negative signs, taking the several segments in a recognized succession. According to Naumann's method the front and rear axis is taken first, next the right and left axis, and lastly the vertical axis. The front, right, and top semi-axes are then assumed to be positive; the rear, left, and bottom semi-axes negative. Thus the octahedron (Fig. 15) is bounded by eight triangles which are equal and similar in form and

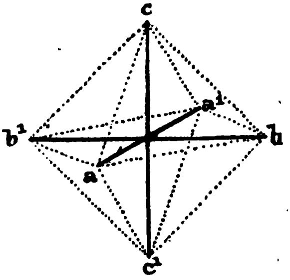


FIG. 15.

position, and these eight faces are by the method just explained successively indicated as follows—

The front, right-hand, top plane	$a\ b\ c$	(wholly positive)	$1\ 1\ 1$
The front, left-hand, top plane	$a\ b'\ c$		$1\ \bar{1}\ 1$
The rear, right-hand, top plane	$a'\ b\ c$		$\bar{1}\ 1\ 1$
The rear, left-hand, top plane	$a'\ b'\ c$		$\bar{1}\ \bar{1}\ 1$
The front, right-hand, bottom plane	$a\ b\ c'$		$1\ 1\ \bar{1}$
The front, left-hand, bottom plane	$a\ b'\ c'$		$1\ \bar{1}\ \bar{1}$
The rear, right-hand, bottom plane	$a'\ b\ c'$		$\bar{1}\ 1\ \bar{1}$
The rear, left-hand, bottom plane	$a'\ b'\ c'$	(wholly negative)	$\bar{1}\ \bar{1}\ \bar{1}$

13. *Hemihedrism*, etc. A crystal whose symmetry conditions the crystallographic identity of all its faces is called a *simple form*. Several distinct simple forms united in a single crystal make up a *combination*. A crystal in which symmetry is satisfied by the full number of pairs of faces is termed *holohedral* (whole-faced). Among crystals that have more than one plane of symmetry (*i. e.* in all except the monoclinic and triclinic systems) we meet with forms that contain only half the number of possible faces, and a correspondingly less degree of symmetry; such forms are termed *hemihedral* (half-faced). In the isometric, tetragonal, and hexagonal systems, which contain more than three planes of symmetry, the divisibility of holohedral crystals into equal and similar parts by means of planes of symmetry may be brought about in more than one way, and in these cases there are several kinds of hemihedrism possible. As far as has been observed, a mineral crystallizes either exclusively in holohedral forms, or exclusively in hemihedral forms, never in both; and moreover only in one kind of hemihedrism (where several kinds are possible). In one kind of hemihedrism each face of a crystal has a corresponding face parallel to it (as in the pentagonal dodecahedron, Fig. 29), and this is defined as *parallel hemihedrism*. On the other hand, in *inclined hemihedrism*, a crystal possesses no parallel faces.

In Naumann's and Weiss's systems of notation hemihedrism is indicated in the form of a fraction in which the symbol of the holohedral form stands as the dividend and the figure 2 as the divisor. For example—

Dyakisdodecahedron $\frac{m\,O\,n}{2}$ (Naumann),
$\frac{1}{2}\,(a : m\,a : n\,a)$ (Weiss).
Tetrahedron $\frac{O}{2}$ (Naumann),
$\frac{1}{2}\,(a : a : a)$ (Weiss).

In Miller's mode of notation parallel hemihedrism is expressed by prefixing the Greek letter π; inclined hemihedrism by the Greek letter κ. Thus for the forms in the examples just given we have π $(l\,k\,h)$ and κ $(h\,h\,h)$ respectively.

In the hexagonal system hemihedral forms are again divisible into halves, the resulting form in each case containing only one quarter of the number of faces of the holohedral crystal. Such forms are called *tetartohedral* (quarter-faced).

Crystals which present different forms of symmetry in opposite directions of a crystal axis (usually the principal axis) are said to be *hemimorphous*. An example is given in Fig. 15*a*, which represents a holohedron; but it should be remembered that hemimorphous forms may also occur in hemihedral and tetartohedral crystals.

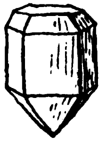


FIG. 15*a*.

13*a*. *Measurement of crystals*. The measurement of the angles of crystals is performed by means of instruments called goniometers, of which there are two kinds. In the *contact goniometer* (Fig. 15*b*) a graduated arc, *a*, to which a steel straight-edge is fixed, moves in a groove of an arc *b* of the same radius. This arc is provided with two zero marks, *z*, z^1, and has attached to it a straight-edge *d* similar to *b*. The crystal is placed at *o* with one of the two faces, the intersecting angle of which is to be measured, against the arm *d*, and the arc *a* is then turned until the chamfered edge of the arm *c* is in close contact with the other crystal face. In this position the two arms describe the required interfacial angle, which can now be read off the divided arc. This hand instrument is only applicable to large crystals, and gives readings to whole degrees only. For small crystals resort must be had to the *reflecting goniometer*, one of the simpler forms of which is shown in Fig. 15*c*. The principles which guide the use of this instrument will be apparent by a reference to Fig. 15*d*. Let the crystal, of which the interfacial angle *a o b* is required, be so fixed to the axis of a graduated circle that the edge *o* is coincident with that axis, *i. e.* remains stationary during a complete revolution of the circle and the attached crystal. A ray of light *x*, falling upon the plane *a o*, will be reflected in the direction of the eye at *z*. If now the crystal be revolved round the edge *o* until the same ray of light after being reflected by the crystal face *o b* again reaches the eye in its unaltered position at *z*, then the plane *o b* must be in a position (indicated by dotted lines) parallel to that originally occupied by the plane *a o*, and obviously the angle through which the graduated circle has moved is equal to

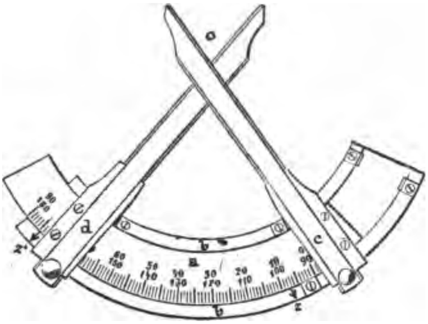


FIG. 15*b*.

the interfacial angle *a o b*. In Fig. 15*c* *k* is a movable pin terminating in a small metal plate, to which the crystal is attached by means of beeswax. This contrivance can be so adjusted that the edge of the crystal is in a line with the axis of the divided circle L. The beam of light which

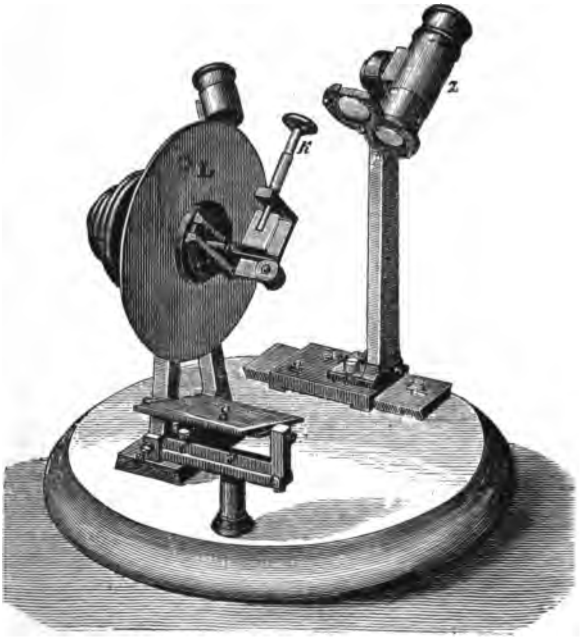


FIG. 15*c*.

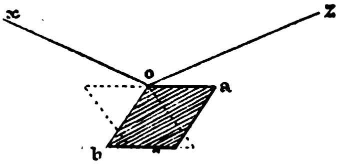


FIG. 15*d*.

serves as a signal is preferably supplied by a lamp screened by a tin plate in which two narrow slits in the form of a cross have been cut. The lamp should be in as elevated and distant a position as is practicable. The direct image of the signal as reflected by the mirror *s*, and the reflection from the crystal are simultaneously observed through the telescope *z*. The circle L has its limb divided into single or half degrees, and by the aid of a vernier allows angles to be read to minutes or half-minutes.

CHAPTER III

THE ISOMETRIC SYSTEM

14. *Crystal axes and symmetry.* In the isometric system there are three crystal axes right-angled to each other and of equal length. The holohedral forms are possessed of three principal planes of symmetry, normal to each other, and six ordinary planes of symmetry. The position of these planes is readily seen by drawing their outlines upon the six faces of a cube, as shown in Fig. 16.

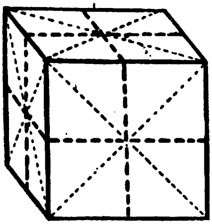


Fig. 16.

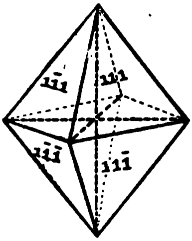


Fig. 17.

15. The *Octahedron* (Fig. 17) is contained by eight equal equilateral triangles. The angle over two adjoining faces is

109° 28′. Each face intercepts the three axes at the unit distance.

Symbols: O . . . . (N)[1]
$a : a : a :$ . . . . (W)
$(h\ h\ h) = (1\ 1\ 1) = 1$ . . . . (M)

16. The *Cube* (Hexahedron) (Fig. 18) is bounded by six equal squares. The dihedral angle is 90°. Each face cuts one of the axes under right angles at the unit distance, and is parallel with the other two axes.

Symbols: $\infty O \infty$ . . . . (N)
$a : \infty a : \infty a$ . . . . (W)
$(h\ o\ o) = (1\ 0\ 0)$ . . . . (M)

17. The *Rhombic Dodecahedron* (Fig. 19) is contained by twelve equal rhombs. The dihedral angles are 120°.

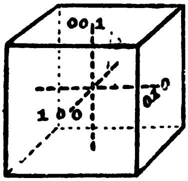


FIG. 18.

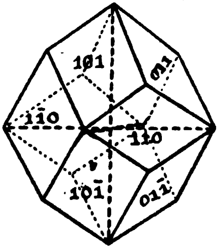


FIG. 19.

There are six three-sided and six four-sided solid angles. The axes lie between opposite pairs of the latter. Each face intercepts two of the axes at the unit distance, while it is parallel with the third.

Symbols: $\infty O\ O = \infty O$ . . . . (N)
$a : a : \infty a$ . . . . (W)
$(h\ h\ o) = (1\ 1\ 0)$ . . . . (M)

---

[1] Here and on succeeding pages the several notations are distinguished by the initial letters N (Naumann), W (Weiss), and M (Miller) respectively.

18. The *Triakisoctahedron* (Three-faced Octahedron) (Fig. 20) is bounded by twenty-four equal isosceles triangles. Its form is that of a regular octahedron, each face of which is surmounted by a three-sided pyramid. Of the solid angles eight are three-sided, and six are eight-sided. The axes lie between pairs of the latter. Each face intercepts two of the axes at the normal distance, and the third at a distance *m*, which is greater than the unit distance. The value of the interfacial angles, both over the longer and shorter edges, obviously varies with the dimension of *m*; it usually lies between 141° 3′ and 153° 28′.

Symbols: $m\,O\,O = m\,O$ . . . . (*N*)
$a : a : m\,a$ . . . . (*W*)
$h\,h\,l\,(h > l)$; e.g. (2 2 1) or (3 3 1) . (*M*)

19. The *Icositetrahedron* (Trapezohedron, Deltohedron) shown in Fig. 21 is enclosed by twenty-four equal trapezoids

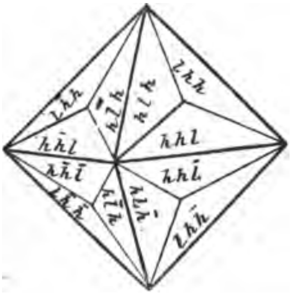


Fig. 20.

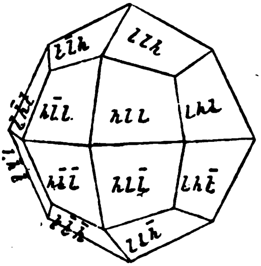


Fig. 21.

(see Fig 7). Of the twenty-two solid angles eight are three-sided, each being formed by three of the shorter edges; eight are four-sided, and formed by two longer and two shorter edges, while the remaining six solid angles are four-sided, each formed by four of the longer edges. The axes lie between the last-mentioned solid angles. Each face intercepts one of the axes at the unit distance, and each of the other two axes at a distance *m* which is greater than 1, usually 2, 2½, or 3. The interfacial angles vary with the distance *m* from 131° 49′ to 146° 27′.

Symbols: *m O m* . . . . (*N*)
a : *m a* : *m a* . . . . (*W*)
h l l ($h > l$); e.g. (2 1 1) or (3 1 1) . (*M*)

20. The *Hexakisoctahedron* (Six-faced Octahedron) (Fig. 22) is bounded by forty-eight scalene triangles. Of the twenty-six solid angles twelve are four-sided, formed by two short and two medium edges; eight are six-sided, formed by three short and three long edges; six are eight-sided, formed by four long and four medium edges. The axes lie between the last-mentioned solid angles. Each face intercepts one axis at the unit distance, another at a distance *m* which is > 1, and the third at a distance *n* which is greater than *m*. The dihedral angles over the several edges differ in the same crystal, and they moreover vary according to the value of *m* and *n* in different crystals. They are usually from 150° to 162°.

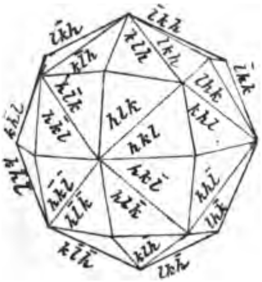


FIG. 22.

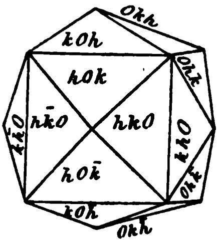


FIG. 23.

Symbols: *m O n* . . . . (*N*)
a : *m a* : *n a* . . . . (*W*)
h k l ($k > l$; $h > k$); all whole numbers, e.g. (3 2 1) or (4 2 1) . . . . (*M*)

21. The *Tetrakishexahedron* (Four-faced cube) (Fig. 23), contained by twenty-four equal isosceles triangles, represents the form of a cube, the faces of which are surmounted by obtuse four-sided pyramids. There are fourteen solid angles, eight of which are six-sided, and formed by alternately longer and shorter edges. The remaining six solid angles are four-sided, formed by short edges. The axes lie between the four-sided solid angles. Each face intercepts one of the axes at the unit distance, runs parallel with the second, and intercepts the third at a distance n which is greater than 1. The interfacial angles over the edges, which are parallel to the axes, become smaller with an increase of n, while those over the polar edges increase with n. Thus for $n = 2$ all the interfacial angles are equal, viz. 143° 8′; if $n = 3$ the dihedral angles over the cube edges are 126° 52′, those over the polar edges are 154° 9′.

Symbols: $\infty O n$ . . . . (*N*)
$a : n a : \infty a$ . . . . (*W*)
$h k O$; e.g. (2 1 0), (3 1 0) . . . . (*M*)

22. *Hemihedral forms.* It has been explained in par. 13 that the suppression of one-half the number of faces (or group of faces) in a holohedral crystal, and the attendant expansion of the remaining half, will give rise to half-faced or hemihedral forms. All the holohedral solids above described (with the obvious exception of the cube and rhombic dodecahedron) yield hemihedral forms. Since either half of the number of faces produces a hemihedron, it is evident that from each holohedron may be derived two half-faced forms, exactly alike but differing in position with regard to the axes of symmetry. In order to distinguish between the two hemihedra it is customary to describe them as positive (+) and negative (−) respectively. The hemihedral crystals of the isometric system are described in the next six paragraphs.

23. The *Tetrahedron* is derived by producing alternate

faces of the octahedron. It is contained by four equal equilateral triangles, the interfacial angle being 70° 32′. The axes lie between the centres of opposite edges. The annexed figure (Fig. 24) represents a positive tetrahedron, the faces of which correspond with the octahedral faces 111, $\bar{1}\bar{1}1$, $1\bar{1}\bar{1}$, $\bar{1}1\bar{1}$ (compare Fig. 17), while the negative tetrahedron conforms to the faces $1\bar{1}1$, $\bar{1}11$, $11\bar{1}$, $\bar{1}\bar{1}\bar{1}$. By turning the positive tetrahedron round the principal axis to the extent of 90°, it attains the position of its negative counterpart.

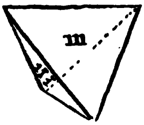


FIG. 24.

$$\text{Symbols: } +\frac{O}{2} \text{ and } -\frac{O}{2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (N)$$

$$\tfrac{1}{2}\,(a : a : a) \text{ and } \tfrac{1}{2}\,(a : \bar{a} : a) \quad . \; . \; . \quad (W)$$

$$\kappa\,(h\,h\,h) \text{ and } \kappa\,(h\,\bar{h}\,h) \quad . \; . \; . \; . \; . \; . \quad (M)$$

24. The *Deltoid-dodecahedron* (Fig. 25), bounded by twelve equal deltoids, is the hemihedral derivative of the triakisoctahedron, its faces corresponding with alternative groups of three faces of the latter. The axes lie between opposite four-sided solid angles. The dihedral angles vary according to the value of *m*, as pointed out in par. 18. The positive form has the faces $(h\,h\,l,\; l\,h\,h,\; h\,l\,h)$, $(h\,\bar{l}\,h,\; h\,\bar{h}\,l,\; l\,\bar{h}\,\bar{h})$, etc., of the triakisoctahedron (Fig. 20). The negative form has the faces $(h\,\bar{h}\,l,\; h\,\bar{l}\,h,\; l\,\bar{h}\,h)$, $(h\,h\,l,\; l\,h\,\bar{h},\; h\,l\,\bar{h})$, etc.

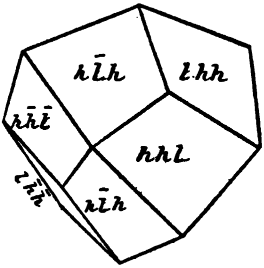


FIG. 25.

$$\text{Symbols: } +\frac{m\,O}{2} \text{ and } -\frac{m\,O}{2} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (N)$$

$$\tfrac{1}{2}\,(a : a : m\,a) \text{ and } \tfrac{1}{2}\,(a : \bar{a} : m\,a) \quad . \quad (W)$$

$$\kappa\,(h\,h\,l) \text{ and } \kappa\,(h\,\bar{h}\,l) \quad . \; . \; . \; . \; . \; . \quad (M)$$

25. The *Triakistetrahedron* (Fig. 26) is composed of

twenty-four equal isosceles triangles, and resembles a tetrahedron each plane of which is replaced by a low three-sided pyramid. It is derived from the icositetrahedron by the extension of alternate groups of three faces. The interfacial angles vary as in the holohedral form (see par. 19). The axes lie between the centres of opposite longer edges. The positive form has the faces $(h\,l\,l,\ l\,h\,l,\ l\,l\,h)$, $(h\,l\,l,\ l\,\bar{h}\,l,\ l\,l\,\bar{h})$, etc., of the icositetrahedron (compare Fig. 21), while the negative hemihedron is produced from the alternate group of faces $(h\,l\,l,\ l\,\bar{h}\,l,\ l\,l\,h)$, $(h\,l\,l,\ l\,h\,l,\ l\,l\,\bar{h})$, etc.

$$\text{Symbols: } +\frac{m\,O\,m}{2} \text{ and } -\frac{m\,O\,m}{2} \quad . \quad . \quad . \quad . \quad . \quad (N)$$

$$\tfrac{1}{2}\,(a : m\,a : m\,a) \text{ and } \tfrac{1}{2}\,(a : m\,\bar{a} : m\,a) \quad (W)$$

$$\kappa\,(h\,l\,l) \text{ and } \kappa\,(h\,l\,l) \quad . \quad . \quad . \quad . \quad . \quad (M)$$

26. The *Hexakistetrahedron* (Fig. 27) is contained by twenty-four equal scalene triangles, and has the appearance of a tetrahedron the faces of which are replaced by low six-sided pyramids. It is derived by inclined hemihedrism from the hexakisoctahedron, its faces conforming with alternate groups of six faces of the latter. The axis lies between opposite four-sided solid angles, the remaining solid angles being six-sided. The dihedral angles vary, as in the holohedral form. The positive hexakistetrahedron has the faces noted on Fig. 22, viz. $(h\,k\,l,\ k\,h\,l,\ h\,l\,k,\ l\,h\,k,\ k\,l\,h,\ l\,k\,h)$, $(h\,\bar{k}\,l,\ k\,\bar{h}\,l,\ h\,l\,\bar{k},\ l\,\bar{h}\,\bar{k},\ k\,l\,\bar{h},\ l\,\bar{k}\,\bar{h})$, etc., while the nega-

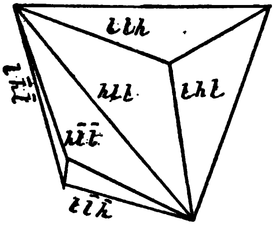


Fig. 26.

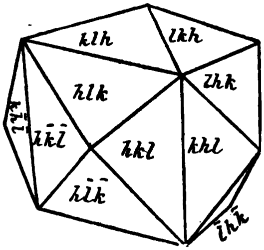


Fig. 27.

tive hexakistetrahedron contains the faces $(h\,k\,l,\ k\,\bar{h}\,l,\ h\,l\,k,\ l\,\bar{h}\,k,\ k\,l\,h,\ l\,\bar{k}\,h)$, $(h\,k\,\bar{l},\ k\,h\,\bar{l},\ h\,l\,\bar{k},\ l\,h\,\bar{k},\ k\,l\,\bar{h},\ l\,k\,\bar{h})$, etc.

Symbols: $+\dfrac{m\,O\,n}{2}$ and $-\dfrac{m\,O\,n}{2}$ . . . . . . (*N*)

$\frac{1}{2}\,(a : m\,a : n\,a)$ and $\frac{1}{2}\,(a : m\,\bar{a} : n\,a)$. (*W*)

$\kappa\,(k\,h\,\bar{l})$ and $\kappa\,(h\,\bar{k}\,\bar{l})$ . . . . (*M*)

27. The *Dyakisdodecahedron* (Diplohedron) is contained by twenty-four equal trapeziums, each of which has two equal and two unequal sides. The edges of the crystal are therefore of three different lengths. The solid angles are partly three-sided and partly four-sided; the latter are of two kinds. The axes lie between those four-sided solid angles which are formed by the meeting of two pairs of equal edges. The dyakisdodecahedron is, like the hexakistetrahedron, derived from the hexakisoctahedron; the produced faces, however, are not alternate groups of six, but alternate pairs adjoining on the octahedral edges. The resulting form is one of parallel hemihedrism, since each face has its parallel counterpart. Fig. 28 shows a positive dyakisdodecahedron, the faces of which, corresponding with those of the holohedral form (Fig. 22), being $(h\,k\,l,\ h\,k\,\bar{l})$, $(h\,\bar{k}\,l,\ h\,\bar{k}\,\bar{l})$, etc. The negative crystal would have the faces $(h\,l\,k,\ h\,\bar{l}\,k)$, $(h\,l\,\bar{k},\ h\,\bar{l}\,\bar{k})$, etc. In Naumann's notation the distinction between the hexakistetrahedron and dyakisdodecahedron is shown by the symbol of the latter being placed in square brackets.

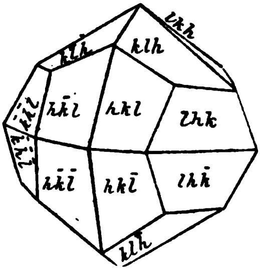


FIG. 28.

Symbols: $+\left[\dfrac{m\,O\,n}{2}\right]$ and $-\left[\dfrac{m\,O\,n}{2}\right]$ . . . (*N*)

$\frac{1}{2}\,(a : m\,a : n\,a)$ and $\frac{1}{2}\,(a : n\,a : m\,a)$. (*W*)

$\pi\,(h\,l\,k)$ and $\pi\,(h\,k\,l)$. . . . . . (*M*)

28. The *Pentagonal dodecahedron* (Fig. 29) is contained by eight equal pentagons, each of which is made up of four equal sides, and a fifth longer than the others. There are three pairs of these longer (polar) edges, each pair being parallel to one of the crystal axes. The axes, therefore, lie between the centres of opposite polar edges. The pentagonal dodecahedron is the parallel-hemihedral form of the four-faced cube, with alternate faces of which it corresponds. The positive form contains the faces $h\ k\ O$, $h\ \bar{k}\ O$, $k\ O\ h$, $k\ O\ \bar{h}$, $O\ h\ k$, $O\ h\ \bar{k}$, etc., of Fig. 23. The negative form has the alternate faces $h\ O\ k$, $h\ O\ \bar{k}$, $k\ h\ O$, $\bar{k}\ h\ O$, $O\ k\ h$, $O\ \bar{k}\ h$, etc. This form is shown in Fig. 29.

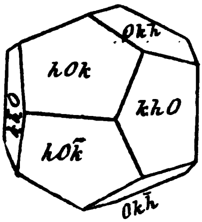


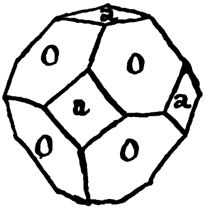
FIG. 29.

Symbols: $+\dfrac{\infty\ O\ n}{2}$ and $-\dfrac{\infty\ O\ n}{2}$ . . . . . (*N*)

$\frac{1}{2}\ (a : n\ a : \infty\ a)$ and $\frac{1}{2}\ (a : \infty\ a : n\ a)$ (*W*)

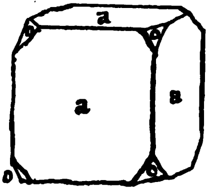
$\left.\begin{array}{l}\pi\ (k\ h\ O) \text{ and } \pi\ (h\ k\ O) \\ \text{e.g. } \pi\,(2\ 1\ 0) \text{ and } \pi\,(1\ 2\ 0)\end{array}\right\}$ . . . . (*M*)

29. *Combinations of isometric forms.* It has already been explained (par. 13) that an individual crystal may be contained by faces belonging to two or more distinct simple forms, presenting what is called a "combination." The several parts of a combination may be all holohedral forms, or all hemihedral forms, or they may be partly holohedral and partly hemihedral. The most commonly occurring combinations of crystals in the isometric system are those illustrated by Figs. 30 to 43. In the notation of combined forms it is usual to give the symbols of the several faces in the order of their greatest development. Thus Figs. 30 and 31 are combinations of identical forms, but the octahedral face being the larger in Fig. 30, its symbol is written down before that of the cube, while in Fig. 31 the cubical face, being the larger, is placed first in the notation.



$O ; \infty O \infty$

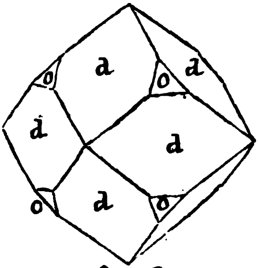
FIG. 30.



$\infty O \infty ; O$

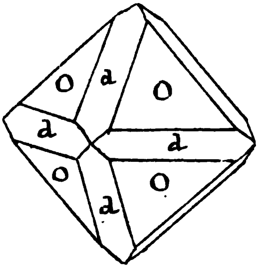
FIG. 31.

30. *Combinations of the Octahedron.* Figs. 30 and 31 show combinations of the octahedron (*O*) and cube (*a*).



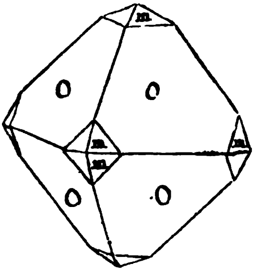
$\infty O ; O$

FIG. 32.



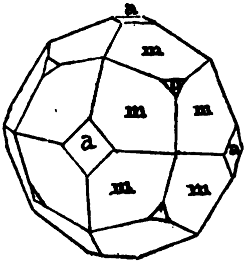
$O ; \infty O$

FIG. 33.



$O ; mOm$

FIG. 34.

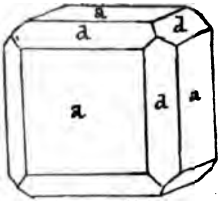


$mOm ; \infty O \infty ; O$

FIG. 35.

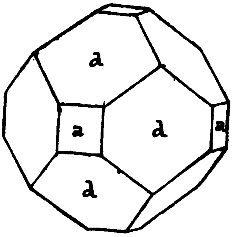
Figs. 32 and 33 show faces of the octahedron (*O*) and rhombic dodecahedron (*d*). Fig. 34 is a combination of the octahedron (*O*) and icositetrahedron (*m*). Fig. 35 is a combination of the octahedron (*O*), icositetrahedron (*m*), and cube (*a*).

31. *Combinations of the Cube.* Figs. 36 and 37 represent combinations of the cube (*a*) and rhombic dodecahedron (*d*). Fig. 38 shows faces of the cube (*a*) and icositetrahedron (*m*); Fig. 39 those of the cube (*a*) and tetrakishexahedron (*n*).



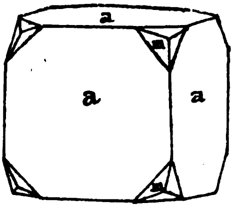
$\infty O \infty$; ∞O

FIG. 36.



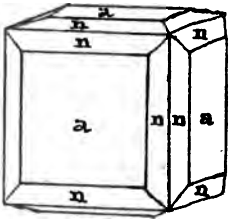
∞O ; $\infty O \infty$

FIG. 37.



$\infty O \infty$; $m O m$

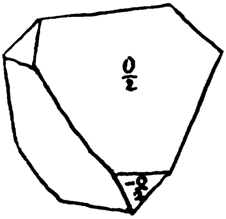
FIG. 38.



$\infty O \infty$; $\infty O n$

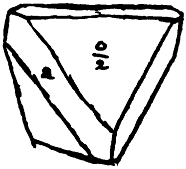
FIG. 39.

32. *Combinations of Hemihedrons.* In Fig. 40 the solid angles of a tetrahedron are replaced by planes of the



$\frac{O}{2} ; -\frac{O}{2}$

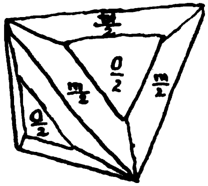
FIG. 40.



$\frac{O}{2} ; \infty O \infty$

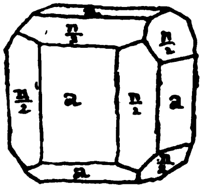
FIG. 41.

negative tetrahedron. In Fig. 41 the edges of the tetrahedron are truncated by faces of the cube. Fig. 42 is a combination of the tetrahedron and triakistetrahedron. Fig. 43



$\frac{O}{2} ; \frac{m O m}{2}$

FIG. 42.



$\infty O \infty ; \frac{\infty O n}{2}$

FIG. 43.

is a combination of the pentagonal dodecahedron $\left(\frac{n}{2}\right)$ and cube (*a*).

CHAPTER IV

THE TETRAGONAL SYSTEM

33. *Crystal axes and symmetry.* In the tetragonal system[1] the two lateral axes are right-angled and of equal length, while the principal axis stands perpendicular to, and is either longer or shorter than, the lateral axes. The latter occupy the position either of diagonals or diameters of a square, a distinction which gives rise to two kinds of crystals, viz. those of the *first order* (proto-pyramids and prisms), and those of the *second order* (deutero-pyramids and prisms). Fig. 44 shows the position of the axes in crystals of the first order; Fig. 45 that in crystals of the second order.

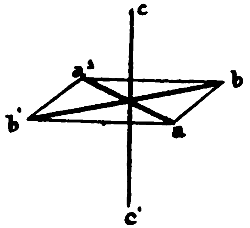


FIG. 44.

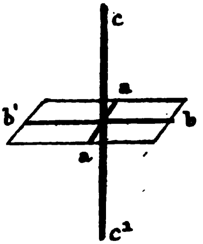


FIG. 45.

Of the five planes of symmetry four intersect in the principal crystal axis under angles of 45°, while the fifth, the chief plane of symmetry, in which lie the lateral crystal axes, is normal to the others. The intersection of the principal and lateral planes of symmetry is shown by the lines $a\ a^1$, $b\ b^1$, $A\ A^1$, and $B\ B^1$ in Fig. 46.

---

[1] It has also been called the *dimetric system*, but since the axes in the hexagonal system are likewise dimetric the appellation is not characteristic.

For convenience of description it is customary to place the principal crystal axis vertical; the principal plane of symmetry then lies horizontally, and is therefore usually spoken of as the *basal* plane of symmetry. The general symbols for the system are $m\,P$, $a : n\,a : m\,c$, and $h\,k\,l$. In combinations, the method of notation may be changed according as we assign one or other of the faces to the unit parameter. Thus in the case of three pyramidal planes of different steepness (Fig. 47), we may assume either x, or y, or z to be = 1; then the notation for the three planes, supposing the height to be in the proportion of 1 : 2 : 3, will be as follows—

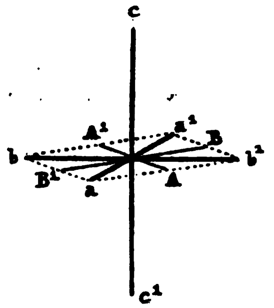


FIG. 46.

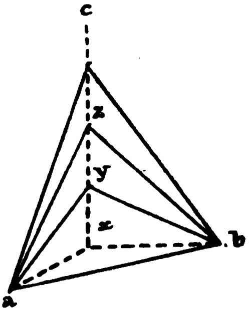


FIG 47.

for $x = 1$ P, $2\,P$, $3\,P$, corresponding with 1 1 1, 2 2 1, 3 3 1
for $y = 1$ $\frac{1}{2}\,P$, P, $\frac{3}{2}\,P$,, ,, 1 1 2, 1 1 1, 3 3 2
for $z = 1$ $\frac{1}{3}\,P$, $\frac{2}{3}\,P$, P ,, ,, 1 1 3, 2 2 3, 1 1 1

34. The *Tetragonal Pyramid* (Square Octahedron) is contained by eight equal isosceles triangles. The basal edges form a square, as in the regular octahedron, but the dihedral angles vary with the length of the principal axis. The pyramid is acute or obtuse, according to whether the principal axis is longer or shorter than the lateral axes. Of

the solid angles, the four lateral angles and the two polar angles are respectively equal. The principal axis extends between the two polar angles. In the *proto-pyramid* the lateral axes lie between opposite basal solid angles, as in Fig. 48. Each plane is intercepted by the two lateral axes at the unit distance, and by the principal axis at the distance m, which is greater or less than 1.

Symbols: 1 1 $m\ P$, contracted to $m\ P$ or simply P (*N*)
$a : a : m\ c$, contracted to $a : a : c$ . . (*W*)
$h\ h\ l$ . . . . (*M*)

In the *deutero-pyramid* (Fig. 49) each face is cut by one lateral axis at the normal distance, and is parallel to the other. The principal axis cuts all faces at the distance m. The lateral edges are equal to the lateral axes.

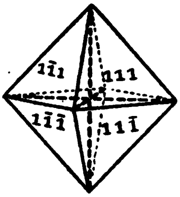


FIG. 48.

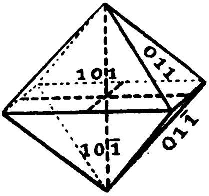


FIG. 49.

Symbols: 1 ∞ $m\ P$, contracted to $m\ P\ \infty$, or
simply $P\ \infty$ . . . . (*N*)
$a : \infty\ a : m\ c$, contracted to $a : \infty\ a : c$ (*W*)
$h\ 0\ l$ . . . . (*M*)

35. The *Ditetragonal Pyramid* (Fig. 50) is formed by two eight-sided pyramids, bounded by sixteen equal scalene triangles. The dihedral angles over the polar edges are alternately larger and smaller. The interfacial angles over the basal edges are all equal, but the plane angles formed by the basal edges are alternately larger and smaller, as

shown in Fig. 51. A moment's consideration will show that the basal plane cannot be a regular eight-sided figure. In the regular octagon (Fig. 52), the parameter $c\,a = 1$, angle $c\,a\,b = 67° 30'$; hence $c\,b = n$ = tang. $67° 30' = 2{\cdot}414$, thus giving for n an irrational value which does not occur in any natural crystal. For $n = \frac{3}{2}$ the angles of the basal octagon in Fig. 51 would be alternately 112° 36′ and 158° 24′.

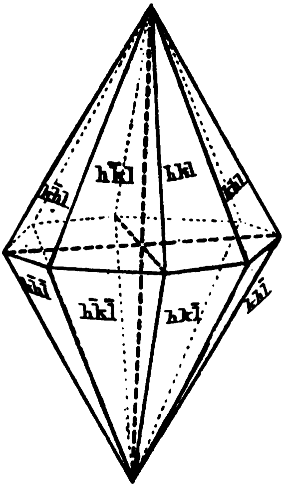


FIG. 50.

The principal axis connects the two eight-sided solid angles. The lateral axes lie between alternate opposite basal, four-sided, solid angles. For purposes of notation it is immaterial whether the faces are referred to the lateral axes proper or to the intermediate axes. Fig. 51 explains this, where the lateral axes are indicated by firm lines, and the intermediate axes by dotted lines. Each face is intercepted

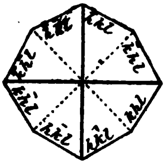


FIG. 51.

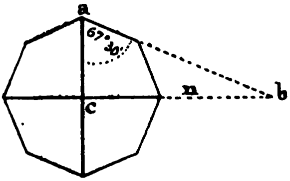


FIG. 52.

by the principal axis, and one of the lateral axes at the normal distance, and by the other lateral axis at a distance n.

Symbols: $m\,P\,n$ . . . . (*N*)
$a : n\,a : m\,c$ . . . . (*W*)
$h\,k\,l$. . . . . (*M*)

36. The *Tetragonal Prism* (Right Square Prism) is contained by two equal squares (the basal planes) and four equal rectangles (the lateral faces). All angles are right angles. The principal axis joins the centres of the basal planes. In the proto-prism (Fig. 53) the lateral axes extend between the centres of opposite vertical edges.

Symbols: $\infty P\,1\,1$, or simply ∞P for the vertical
faces, and $O\,P$ for the basal planes.
For the complete crystal, therefore,
$\infty P + O\,P$ . . . . (*N*)
$a : a : \infty c + \infty a : \infty a : c$ . . . . . (*W*)
$(h\,h\,O) + (O\,O\,l)$ . . . . (*M*)

In the deutero-prism the lateral axes lie between centres of opposite planes.

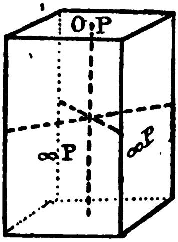


Fig. 53.

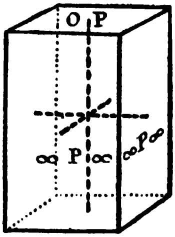


Fig. 54.

Symbols: $\infty P \infty\,1$ contracted to $\infty P \infty + O\,P$ (*N*)
$a : \infty a : \infty c + \infty a : \infty a : c$. . . . (*W*)
$(h\,O\,O) + (O\,O\,l)$ . . . . (*M*)

37. The *Ditetragonal Prism* is contained by eight equal rectangles and two octagons, the angles of which are

alternately larger and smaller, as explained in par. 35. The principal axis lies between the centres of the octagons, the lateral axes between centres of opposite vertical edges.

Symbols: $\infty P n + O P$ . . . . (*N*)
$a : n a : \infty c + \infty a : \infty a : c$ . . . . (*W*)
$(h\, k\, O) + (O\, O\, l)$ . . . . (*M*)

38. The *Tetragonal Sphenoid* (Tetragonal tetrahedron) is the hemihedral derivative of the tetragonal pyramid. It is contained by four equal isosceles triangles. The two horizontal (polar) edges are equal, and they lie in directions right-angled to each other. The four middle edges are all equal, but they differ in length from the polar edges. The dihedral angle over the polar edges, depending as it does on the polar angle of the original pyramid, is acute or obtuse, whence we distinguish between the acute sphenoid (Fig. 56) and the obtuse sphenoid (Fig. 57). An extension of the octahedral faces (see Fig. 48), $1\,1\,1$, $\bar{1}\,\bar{1}\,1$, $1\,\bar{1}\,\bar{1}$, $\bar{1}\,1\,\bar{1}$, yields the positive

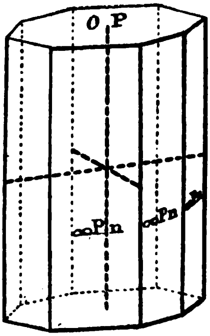


FIG. 55.

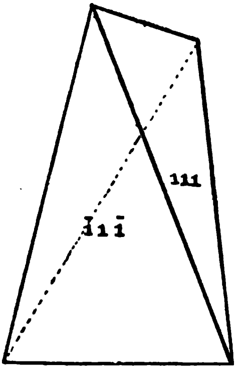


FIG. 56.

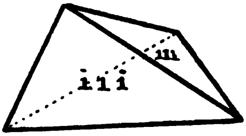


FIG. 57.

sphenoid, while the alternate faces, $1\,\bar{1}\,1$, $\bar{1}\,1\,1$, $1\,1\,\bar{1}$, $\bar{1}\,\bar{1}\,\bar{1}$, produce the negative sphenoid.

Symbols: $\frac{m\,P}{2}$ and $-\frac{m\,P}{2}$. . . . . (*N*)
$\frac{1}{2}\,(a : a : m\,c)$ and $-\,\frac{1}{2}\,(a : a : m\,c)$. (*W*)
$\kappa\,(h\,h\,l)$ and $\kappa\,(h\,\bar{h}\,l)$. . . . . . (*M*)

39. The *Tetragonal Trapezohedron* is derived from the ditetragonal pyramid by the extension of alternate faces of that crystal. It is contained by eight equal trapeziums. The two polar angles are four-sided, the four other solid angles are three-sided. The eight polar edges are equal, the lateral edges alternately longer and shorter. From the faces $h\,k\,l$, $\bar{k}\,h\,l$, $\bar{h}\,\bar{k}\,l$, $k\,\bar{h}\,l$, etc., of the ditetragonal pyramid (Fig. 50) the positive, usually called the *right*, trapezohedron (Fig 58) is obtained, while the faces $k\,h\,l$, $\bar{h}\,k\,l$, $\bar{k}\,\bar{h}\,l$, $h\,\bar{k}\,l$, etc., yield the negative, usually called the *left*, trapezohedron. This kind of trapezohedral hemihedrism is indicated in Miller's notation by the Greek letter τ.

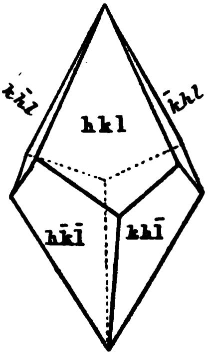


FIG. 58.

Symbols: $\frac{m\,P\,n}{2}\,r$ and $\frac{m\,P\,n}{2}\,l$ . . . . (*N*)
$\frac{1}{2}\,(a : n\,a : m\,c)$ and $\frac{1}{2}\,(n\,\bar{a} : a : m\,c)$. (*W*)
$\tau\,(h\,k\,l)$ and $\tau\,(k\,h\,l)$. . . . . . (*M*)

40. The *Tetragonal Scalenohedron* (Fig. 59) is contained by eight scalene triangles, the alternate interfacial angles, viz. those over the longer edges, being those of the holohedral form. It is, like the trapezohedron, a hemihedral

derivative of the ditetragonal pyramid, with alternate pairs of faces of which it corresponds. Accordingly the faces $(h\ k\ l,\ k\ h\ l)$, $(\bar{h}\ \bar{k}\ l,\ \bar{k}\ \bar{h}\ l)$, $(\bar{k}\ h\ l,\ \bar{h}\ k\ l)$ and $(k\ \bar{h}\ l,\ h\ \bar{k}\ l)$ produce the positive scalenohedron; the alternate pairs of faces the negative form.

Symbols: $\frac{m\,P\,n}{2}$ and $-\frac{m\,P\,n}{2}$ . . . . (*N*)
$\frac{1}{2}\,(a : n\,a : m\,c)$ and $\frac{1}{2}\,(n\,a : a : m\,c)$ (*W*)
$\kappa\ (h\ k\ l)$ and $\kappa\ (k\ h\ l)$ . . . . . . (*M*)

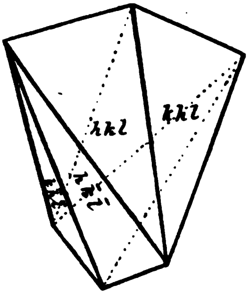


FIG. 59.

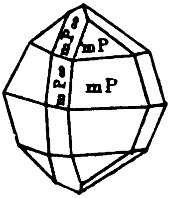


FIG. 60.

41. *Combinations of tetragonal forms.* A combination of several pyramids of the first and second order and of

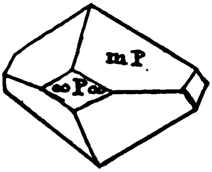


FIG. 61.

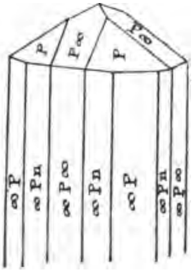


FIG. 62.

different steepness is shown in Fig. 60. In the next figure (Fig. 61) the proto-pyramid has its basal solid angles replaced by faces of the deutero-prism.

In Fig. 62 the sixteen-sided prism is made up of faces of the proto-prism ∞P and deutero-prism $\infty P \infty$, with the vertical edges truncated by faces of the ditetragonal prism $\infty P n$. The terminal pyramid is a combination of the proto-pyramid P and the deutero-pyramid $P \infty$.

Fig. 63 represents a combination of the positive and negative sphenoid. Fig. 64 shows a combination of the proto-pyramid P, having its terminal parts truncated by the basal plane $O P$ of the prism, and the lateral solid angles replaced by faces of the deutero-sphenoid $\frac{P \infty}{2}$.

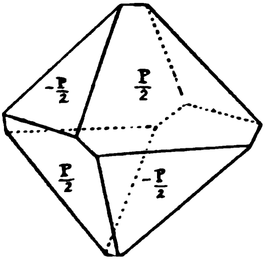


Fig. 63.

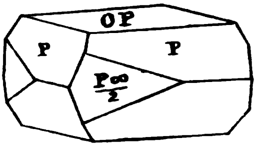


Fig. 64.

CHAPTER V

THE RHOMBIC SYSTEM

42. *Crystal axes and symmetry.* In this system, also called the orthorhombic, or trimetric system, there are three axes of unequal length and right-angled to each other. These crystal axes are also axes of symmetry. None of the

axes is, crystallographically speaking, a principal axis, hence any one may be selected as the vertical axis (c). In practice it is customary to place the brachy-axis (a) towards the observer, with the macro-axis (b) extending from left to right. The lateral axes occupy the position either of diagonals of a rhomb (Fig. 65) or of diameters of a rectangle (Fig. 66). The rhombic and rectangular pyramids and prisms of this system are therefore the equivalents of the pyramids and prisms of the first and second order in the tetragonal system.

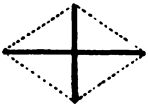


FIG. 65.

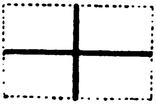


FIG. 66.

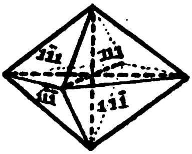


FIG. 67.

43. The *Rhombic Pyramid* (Fig. 67) is bound by eight equal scalene triangles. The polar edges are alternately acute and obtuse; each face is intercepted by the three axes at the unit distances.

Symbols: $m\,P = P$ . . . . (N)
$a : b : m\,c$ . . . . (W)
$(h\,k\,l)$, where $h < k$ and $h \gtrless l$ . . (M)

44. The *Rhombic Prism* is bound by four equal rectangles and two equal rhombs. By an interchange of the axes we obtain three kinds of prisms, viz. a vertical prism and two longitudinal prisms. In the latter the terminal faces meet in a horizontal edge, thus resembling the roof of a house (*doma*), and such prisms are accordingly termed *domes*.

(a) The *Vertical Prism* (Fig. 68). In this prism the chief axis lies between the centres of the rhombic faces, the lateral axes connect centres of opposite vertical edges.

Each vertical face is therefore intercepted by the lateral axes at the normal lengths, and is parallel to the vertical axis, while the basal planes are parallel to the lateral axes, and are intercepted by the vertical axis at the unit distance.

Symbols: $\infty P + O P$ . . . . (*N*)
$a : b : \infty c + \infty a : \infty b : c$ . . . . . (*W*)
$(h\ k\ O) + (O\ O\ l) = (1\ 1\ 0) + (0\ 0\ 1)$. (*M*)

(*b*) The *Macrodome* (Fig. 69). This is a horizontal prism in which the vertical axis occupies the position which the macro-axis occupied in the vertical prism, *i. e.* it lies between the centres of the edges which run parallel to the macro-diagonal axis. The latter connects the centres of the rhombic side faces. Macrodomes are distinguished by the sign – over the letter *P*.

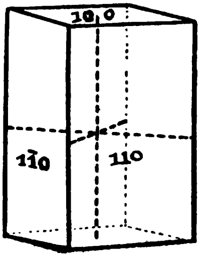


Fig. 68.

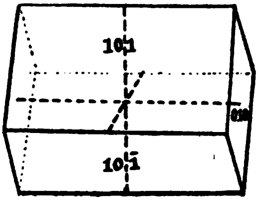


Fig. 69.

Symbols: $\infty \bar{P} \quad + \infty \breve{P} \infty$ . . . . (*N*)
$a : \infty b : c + \infty a : b : \infty c$ . . . . . (*W*)
$(h\ O\ l) \quad + (O\ k\ O) = (1\ 0\ 1) + (0\ 1\ 0)$ (*M*)

(*c*) The *Brachydome* (Fig. 70) is likewise a horizontal prism, but the chief axis lies in the position which the brachy-axis occupied in the vertical prism. The brachy-axis lies between the centres of the rhombic front faces.

Symbols: $\infty \breve{P} \quad + \infty \bar{P} \infty$ . . . . (*N*)
$\infty a : b : c + a : \infty b : \infty c$. . . . . . (*W*)
$(O\,k\,l) \quad + h\,O\,O$. . . . . (*M*)

In all three kinds of prisms $h \gtrless l$, that is to say, the angle between any pair of rectangular faces, may be either acute or obtuse.

45. The *Rectangular Pyramid* (Fig. 71) is contained by four pairs of alternately larger and smaller isosceles triangles. The smaller faces are parallel to the brachy-axis, and are intercepted by the macrodiagonal and vertical axes at unit lengths. The larger faces are parallel to the macrodiagonal and are intercepted by the brachydiagonal and vertical axes. The rectangular pyramid may be looked upon as a combination of the macrodome and brachydome.

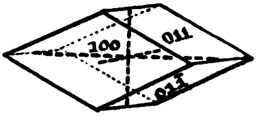


FIG. 70.

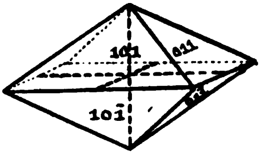


FIG. 71.

Symbols: $\infty P \quad + \infty \breve{P}$ . . . . (*N*)
$a : \infty b : c + \infty a : b : c$ . . . . . . (*W*)
$(h\,O\,l) \quad + (O\,k\,l)$; where $h < k$ and
$h \lessgtr l$. . . . . (*M*)

46. The *Rectangular Prism* (Fig. 72) is contained by six rectangles, of which opposite pairs are equal. Each face is intercepted by one axis, under right angles, and is parallel to the other two axes. A tabular section parallel to the macrodiagonal and vertical axes is called a *macropinacoid* (from *pinax*, a board); a section parallel to the brachy-

diagonal and vertical axes is called a ***brachypinacoid;*** a section parallel to the lateral axes is a ***basal pinacoid.***

	Macropinacoid	Brachypinacoid	Basal pinacoid	
Symbols:	$\infty \bar{P} \infty$	$\infty \breve{P} \infty$	$0 P$ . .	(*N*)
	$a : \infty b : \infty c$	$\infty a : b : \infty c$	$\infty a : \infty b : c$	(*W*)
	$(h\,0\,0)$	$(0\,k\,0)$	$(0\,0\,l)$.	(*M*)

47. The ***Rhombic Sphenoid*** (Figs. 73, 74) is the hemihedral form of the rhombic pyramid. It is contained by four scalene triangles. The terminal edges are horizontal and equal, but their planes, unlike those in the tetragonal sphenoid, intersect under an oblique angle. The four polar edges are alternately equal. In conformity with the proto-pyramid from which it is derived, the sphenoid is either acute (Fig. 73) or obtuse (Fig. 74).

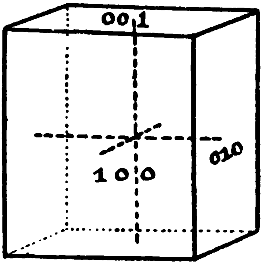


Fig. 72.

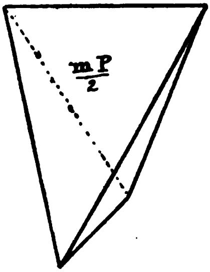


Fig. 73.

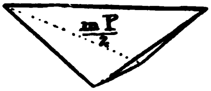


Fig. 74.

Symbols:	$\frac{m\,P}{2}$	and	$-\frac{m\,P}{2}$	(*N*)
	$\frac{1}{2}\,(a : b : m\,c)$	and	$-\frac{1}{2}\,(a : b : m\,c)$.	(*W*)
	$\kappa\,(h\,k\,l)$	and	$\kappa\,(h\,\bar{k}\,l)$ . . .	(*M*)

48. *Combinations of Rhombic forms* (Figs. 75 to 80). Fig. 75 represents a combination of the vertical prism (1 1 0)

and two rectangular pyramids of different steepness (0 1 1) and (0 1 3).

Fig. 76 is a combination of the rhombic prism (1 1 0), the brachypinacoid (0 1 0), the rhombic pyramid (1 1 1), and the square pyramid (0 1 1).

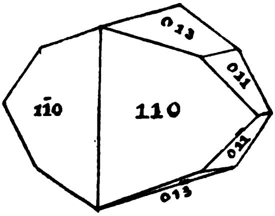


FIG. 75.

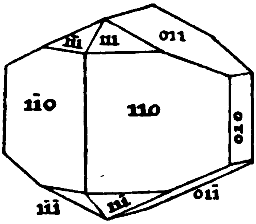


FIG. 76.

Fig. 77 shows the rhombic prism (1 1 0), brachypinacoid (0 1 0), two rhombic pyramids of different steepness (1 1 1) and (1 1 3), two rectangular pyramids of different steepness (0 1 1) and (0 1 3), and the basal plane (0 0 1).

Fig. 78 exhibits faces of the macropinacoid (1 0 0), rhombic proto-prism (1 1 0), rhombic prism (3 1 0), brachypinacoid (0 1 0), and rectangular pyramid (0 1 1).

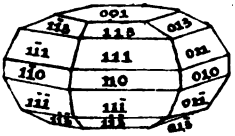


FIG. 77.

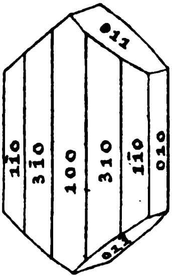


FIG. 78.

Fig. 79 represents a combination of the rhombic sphenoid *k* (1 1 1) = $\left(\frac{P}{2}\right)$, the negative sphenoid $\left(-\frac{P}{2}\right)$, the rhombic prism (1 1 0), and the basal plane (0 0 1).

Fig. 80 is an eight-sided prism showing the faces (1 1 0) and (1 2 0) of two rhombic prisms with different macrodiagonals, surmounted by the rectangular pyramids (1 0 1) and (0 1 1), the polar edges of which are replaced by the sphenoid $\left(\frac{P}{2}\right)$.

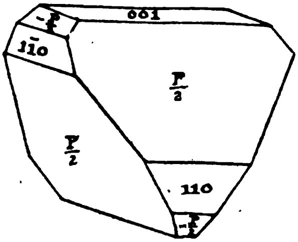


FIG. 79.

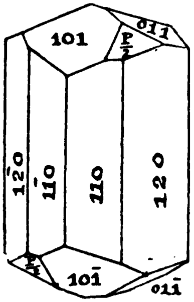


FIG. 80.

CHAPTER VI

THE MONOCLINIC SYSTEM

49. *General characters.* An outline of the monoclinic system (also called the oblique, clinorhombic, and monosymmetric system) has been given in par. 4. The possible forms in this system are those of rhombic and rectangular pyramids, vertical prisms, domes, pinacoids, and sphenoids, differing from similar crystals of the rhombic system in that the plane of the lateral axes is inclined instead of normal to the chief axis.

50. The *Oblique Rhombic Pyramid* (Fig. 81) is contained by eight scalene triangles, opposite pairs of which are equal, that is to say, the upper front faces and the lower rear faces are equal; and the upper rear faces and the lower front faces are equal; the former are the larger. We have practically faces representative of two distinct pyramids, which it is usual to designate as *positive* $(+P)$ and *negative* $(-P)$ *hemi-pyramids*. Thus if the planes $(h\,k\,l)$, $(h\,\bar{k}\,l)$, $(\bar{h}\,k\,l)$, $(\bar{h}\,\bar{k}\,l)$, which face the obtuse angle of the clinodiagonal axis, make up the positive hemi-pyramid, then the planes $(\bar{h}\,k\,l)$, $(\bar{h}\,\bar{k}\,l)$, $(h\,k\,l)$, $(h\,\bar{k}\,l)$, which face the acute angle β, constitute the negative hemi-pyramid).[1] In the subjoined diagrams the faces are marked 1 to 8 in the sequence just given. Fig. 82 is a front view,

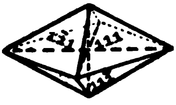


FIG. 81.

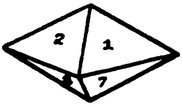


FIG. 82.

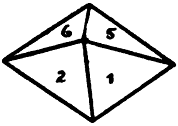


FIG. 83.

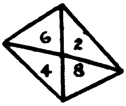


FIG. 84.

Fig. 83 a plan on the plane of the diagonals, and Fig. 84 a side view facing the plane of symmetry. Oblique rhombic pyramids may be acute or obtuse.

$$\text{Symbols: } \overbrace{+mP\text{ and }-mP}^{\text{Acute}} \quad \overbrace{+\frac{1}{m}P\text{ and }-\frac{1}{m}P}^{\text{Obtuse}} \quad . \quad (N)$$

$$\pm a:b:mc \qquad \pm a:b:\frac{1}{m}c \quad . \quad . \quad . \quad (W)$$

$$(h\,k\,l)\text{ and }(\bar{h}\,k\,l)\;h>l \quad (h\,k\,l)\text{ and }(\bar{h}\,k\,l)\;h<l \quad (M)$$

---

[1] In Naumann's original notation this order is reversed, a method which, however, is apt to create confusion, since the practice is in all other cases to consider upper front faces as positive.

51. The *Oblique Rhombic Prism* is bound by four equal rhomboids, the side planes; and two equal rhombs, the basal planes. Of the solid angles the four side angles cut by the orthodiagonal plane are equal; the upper back and lower front angles are acute and equal; the upper front and lower back angles are obtuse and equal.

(*a*) The *Vertical Clinorhombic Prism* (Fig. 85).

Symbols: $\infty P \quad + O P$ . . . . (N)
$a : b : \infty c + \infty a : \infty b : c$. . . . . . ($W$)
$(h\ k\ O) \quad + (O\ O\ l)$ . . . . (M)

(*b*) The *Orthodome*, corresponding with the rhombic macrodome (Fig. 69).

Symbols: $\infty \bar{P} \quad + \infty \not{P} \infty$ . . . . (N)
$a : \infty b : c + \infty a : b : \infty c$. . . . . . ($W$)
$(h\ O\ l) \quad + (O\ k\ O)$ . . . . (M)

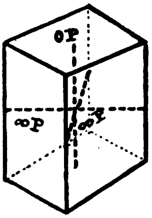


FIG. 85.

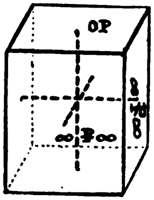


FIG. 86.

(*c*) The *Clinodome*, corresponding with the rhombic brachydome (Fig. 70).

Symbols: $\infty \not{P} \quad + \infty \bar{P} \infty$ . . . . (N)
$\infty a : b : c + a : \infty b : \infty c$. . . . . . ($W$)
$(O\ k\ l) \quad + (h\ O\ O)$ . . . . (M)

52. The *Oblique Rectangular Prism* (Fig. 86) is contained by four rectangles, the side planes; and two basal rhomboids, the opposite faces being equal.

(*a*) The *Orthopinacoid* represents a section parallel with the orthodiagonal and vertical axes.

Symbols: $\infty \bar{P} \infty$ . . . . (*N*)
$a : \infty b : \infty c$ . . . . (*W*)
$(h\ O\ O)$. . . . . (*M*)

(*b*) The *Clinopinacoid* is a section parallel to the clinodiagonal and vertical axes.

Symbols: $\infty \not{P} \infty$ . . . . (*N*)
$\infty a : b : \infty c$ . . . . (*W*)
$(O\ k\ O)$. . . . . (*M*)

(*c*) The *Basal Pinacoid* is a section parallel to the lateral axes.

Symbols: $O\ P$ . . . . (*N*)
$\infty a : \infty b : c$ . . . . (*W*)
$(O\ O\ l)$ . . . . (*M*)

53. *Combinations of Monoclinic forms.* Fig. 87 is a combination of the vertical rhombic prism ($\infty\ P$), the front and rear vertical edges of which are replaced each by two planes of a prism ($2\ 1\ 0 = \tilde{n}\ P$), while the right and left edges are replaced by planes of the clinopinacoid ($\infty\ \not{P}\ \infty$). The

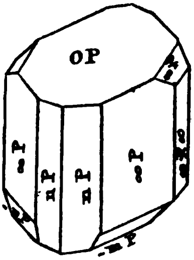


FIG. 87.

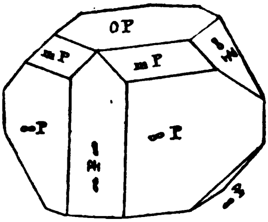


FIG. 87*a*.

latter is surmounted by the clinodome (∞Ꝑ). The rear edges of the top plane (*OP*) and the front edges of the bottom plane are replaced by planes of the proto-pyramid (- *m P*).

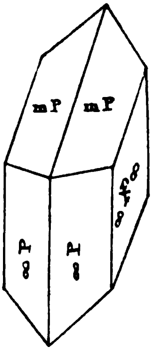


FIG. 88.

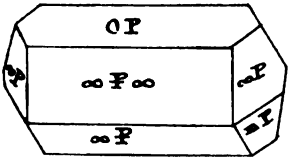


FIG. 89.

Fig. 87*a* shows a vertical prism (∞ *P*) surmounted by a truncated pyramid (*m P*); faces of the orthopinacoid ∞ *P̄* ∞, the clinodome ∞ Ꝑ, and the basal pinacoid *O P*.

Fig. 88 is a combination of the vertical prism (∞ *P*) and clinopinacoid (∞ Ꝑ ∞), surmounted by the proto-pyramid (*m P*).

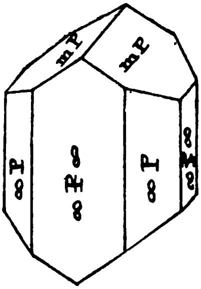


FIG. 90.

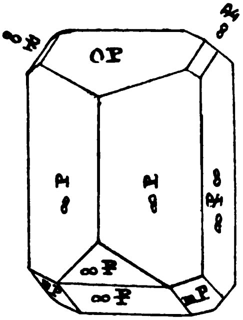


FIG. 91.

Fig. 89 represents the orthopinacoid (∞ ₽ ∞), the upper rear and lower front edges replaced by faces of the orthodome (∞ ₽); the vertical prism (∞P), the hemi-pyramid ($m P$), and the basal pinacoid ($O P$).

In Fig. 90 the vertical prism (∞P) is combined with the orthopinacoid (∞ ₽ ∞) and the clinopinacoid ($\infty \not{P} \infty$), and surmounted by the positive hemi-pyramid ($m P$).

Fig. 91 represents the vertical prism (∞P), the clinopinacoid ($\infty \not{P} \infty$), the clinodome ($\infty \not{P}$), two orthodomes (∞ ₽) of different steepness, the proto-pyramid ($m P$), and the basal pinacoid ($O P$).

CHAPTER VII

THE TRICLINIC SYSTEM

54. *General Characters.* It was already pointed out in par. 5 that the intersections of all three reference axes in the triclinic system are oblique, and that therefore crystals belonging to this system are devoid of any plane of symmetry. Expression is given to this feature by the names "*asymmetric*" and "*anorthic*," under which this system is also known. Each face of an asymmetric crystal has but a single corresponding parallel face, and any one pair of parallel faces constitutes in a crystallographic sense a simple crystal form. Since a closed form demands not less than three pairs of parallel planes, it is obvious that a complete triclinic crystal involves a threefold combination, while, as we have seen, a twofold combination suffices in making up a complete crystal in the other systems.

Any one of the axes of a triclinic crystal may be selected as the vertical axis. Of the lateral axes it is customary to place the brachydiagonal (a) in a position inclining towards the observer, while the macrodiagonal (b) lies transversely. For the determination of a crystal it is requisite to know the value of the angles α, β, and γ; α being the angle between the vertical and macrodiagonal axes (∧ *c o b* in Fig. 92); β that between the vertical and brachydiagonal (∧ *c o a*); γ that between the lateral axes (∧ *a o b*). The angles are those afforded by the front upper right octant *c a b*, so that β is always an obtuse angle, while α and γ may be greater or less than a right angle. The amount of obliquity varies considerably; while it is very marked in some minerals (*e.g.* chalcanthite, axinite), it is so slight in others as to render it difficult to distinguish crystals from monoclinic (*e.g.* microlite, albite) or even isometric forms (*e.g.* cryolite).

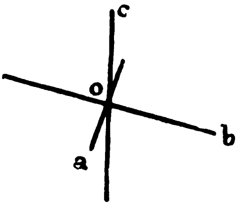


FIG. 92.

The notations under this system are generally analogous to those of the rhombic system.

55. The *Tetarto-Pyramid* is represented by two scalene triangles, which are part of a unit pyramid contained by four pairs of faces, viz.—

$$(1\,1\,1) = (\bar{1}\,\bar{1}\,\bar{1})$$
$$(1\,\bar{1}\,1) = (\bar{1}\,1\,\bar{1})$$
$$(\bar{1}\,1\,1) = (1\,\bar{1}\,\bar{1})$$
$$(\bar{1}\,\bar{1}\,1) = (1\,1\,\bar{1})$$

It should be understood that the complete form, composed of the whole of these eight faces, is merely a theoretical quantity, and that no such crystal as a triclinic octahedron actually occurs in nature. Each of the four sets of faces represents a distinct form, the index of which is indicated by the accent (′) being placed in a characteristic position relative to the letter *P*. Thus—

P' for the front upper right octant.
$'P$ for the front upper left octant.
$P_{,}$ for the front lower right octant.
$_{,}P$ for the front lower left octant.

Symbols: $m\,P'$ and $\frac{1}{m}\,P'$ . . . . (*N*)
$a : b : m\,c$ and $a : b : \frac{1}{m}\,c$ . . . . . . (*W*)
$(h\,k\,l)\ h > l$ and $(h\,k\,l)\ h < l$ . . (*M*)

56. The *Hemi-Prism* is an open form contained by two planes parallel to each other and to the vertical axis. The right (upper and lower) half is distinguished from a left upper and lower half as follows—

Symbols: $\infty\,P'$ and $\infty\,'P$ . . . . (*N*)
$a : b : \infty\,c$ and $a : b' : \infty\,c$ . . . . (*W*)
$(h\,k\,O)$ and $(h\,\bar{k}\,O)$ . . . . (*M*)

57. The *Hemi-Dome* comprises two forms, viz. the macrodiagonal and the brachydiagonal, each being again separable into front and rear, and right and left hemi-domes respectively.

The *front hemi-macrodome* comprises the front upper right and left faces of the pyramid, in which b is extended so that $n = \infty$.

Symbols: $'\bar{P}'\,\infty$ . . . . (*N*)
$a : \infty\,b : c$ . . . . (*W*)
$(h\,O\,l)$ . . . . (*M*)

The *rear hemi-macrodome* similarly represents the lower right and left faces of the pyramid, in which $n = \infty$.

Symbols: $_{,}\bar{P}_{,}\,\infty$ . . . . (*N*)
$a : \infty\,b' : c$ . . . . (*W*)
$(\bar{h}\,O\,l)$ . . . . (*M*)

The *right hemi-brachydome* embodies the faces of the right upper and left lower tetarto-pyramids.

Symbols: $_{,}\breve{P}'\,\infty$ . . . . (*N*)
$\infty\,a : b : c$ . . . . (*W*)
$(O\,k\,l)$ . . . . (*M*)

The *left hemi-brachydome* corresponds with the faces of the left upper and right lower tetarto-pyramids.

Symbols : $'\breve{P}_{,} \infty$ . . . . (N)
$\infty a : b' : c$ . . . . (W)
$(0 \, k \, l)$ . . . . (M)

58. The *Triclinic Pinacoids* are, like the rhombic pinacoids, contained by planes parallel to the vertical and brachydiagonal axes, *i. e.* in the brachypinacoid; or by planes parallel to the vertical and macrodiagonal axes, *i. e.* in the macropinacoid; or by planes parallel to the lateral axes, *i. e.* in the basal pinacoid.

	Brachypinacoid	**Macropinacoid**	**Basal pinacoid**	
Symbols :	$\infty \breve{P} \infty$	$\infty \bar{P} \infty$	$O P$	(N)
	$\infty a : b : \infty c$	$a : \infty b : \infty c$	$\infty a : \infty b : c$	(W)
	(0 1 0)	(1 0 0)	(0 0 1)	(M)

59. *Triclinic combinations.* Fig. 93 shows a combination of the hemi-prism ($\infty \, 'P$ and $\infty \, P'$), the tetarto-pyramid

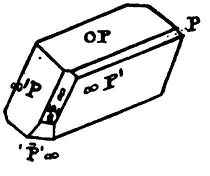


Fig. 93.

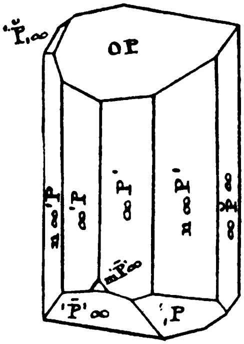


Fig. 94.

(P'), the macropinacoid ($\infty \, \bar{P} \infty$); the macrodome $'P' \infty$, and the basal pinacoid ($O \, P$).

Fig. 94 represents a crystal of albite, in which occur planes of the right and left proto-hemi-prism ($\infty P'$ and $\infty\, 'P$), the brachypinacoid ($\infty P \infty$), and, intermediate between these two, the right and left prisms ($n \infty P'$ and $n \infty\, 'P$). Further, the two macrodomes of different steepness ($'\bar{P}\infty$ and $m\,'P'\infty$), the tetarto-pyramid $_{,}P$, the hemi-brachydome $'\check{P}_{,}\infty$, and the basal plane $O\,P$.

CHAPTER VIII

THE HEXAGONAL SYSTEM

60. *Crystal axes and symmetry.* The Hexagonal, also called the *Rhombohedral* system is, as regards physical and geometrical character of the crystals, closely related to the tetragonal. Both possess a single principal plane of symmetry, and therefore one principal crystal axis, and in both the ordinary and principal planes of symmetry are normal to each other. The ordinary planes of symmetry in the hexagonal system are six in number (as against four in the tetragonal system), and they intersect each other under angles of 30°. There are three lateral axes of equal length, intersecting under angles of 60°. They are formed by the lines of intersection of the principal plane of symmetry and three alternate ordinary planes of symmetry. Obviously, complete symmetry is satisfied whichever set of three planes of symmetry we may choose, and we have accordingly forms of the first and second orders, the lateral axes of the latter being at an angular distance of 30° from those of the former (Figs. 95 and 96).

61. The *Hexagonal Pyramid* is contained by twelve equal isosceles triangles. The six equal basal solid angles are four-sided; the polar angles are six-sided. The principal axis lies between the latter. The pyramids are acute or obtuse, according to whether the principal axis is longer or

shorter than the lateral axes. The proportion $a : c$ is an irrational value which differs in different minerals. In

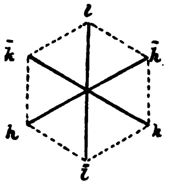


FIG. 95.

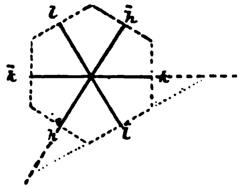


FIG. 96.

proto-pyramids, or pyramids of the *first order* (Fig. 97), the lateral axes lie between opposite four-sided solid angles. Each face cuts the principal and two of the lateral axes at unit distances, and is parallel to the third lateral axis.

Symbols: $m\ P$, or simply P. . . . . (N)
$a : a : \infty a : m c$ . . . . (W)
$(h\ O\ \bar{h}\ l) = (1\ 0\ \bar{1}\ 1)$ . . . . . . (M)

In *deutero-pyramids*, or pyramids of the *second order* (Fig. 98), the lateral axes lie between centres of opposite basal

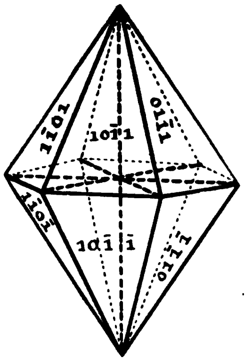


FIG. 97.

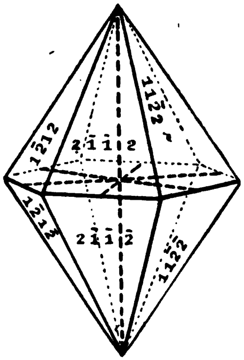


FIG. 98.

edges. Each face intercepts the principal and one lateral axis at the normal distances, and the other two axes at double the unit distance (see Fig. 96).

Symbols: $m\,P\,2$, or simply $P\,2$ . . . . (*N*)
$a : 2a : 2a : mc$ . . . . (*W*)
$(k\,k\,\bar{h}\,l)$ where $2k = h$ . . . . . . (*M*)

62. The *Hexagonal Prism* is contained by six equal rectangles and two equal regular hexagons. The principal axis extends between the centres of the hexagons. In the prism of the *first order* (Fig. 99) the lateral axes lie between centres of opposite vertical edges.

Symbols: ∞P . . . . (*N*)
$a : a : \infty a : \infty c$ . . . . (*W*)
$(h\,O\,\bar{l}\,O) = (1\,0\,\bar{1}\,0)$ . . . . (*M*)

In the *deutero-prism*, or prism of the *second order* (Fig. 100), which results from turning the proto-prism round the principal axis to the extent of 30°, the lateral axes join the centres of the rectangles.

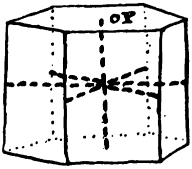


FIG. 99.

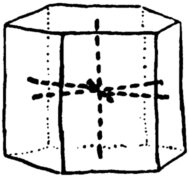


FIG. 100.

Symbols: $\infty P\,2$ . . . . (*N*)
$a : 2a : 2a : \infty c$ . . . . (*W*)
$(h\,h\,\bar{l}\,O) = (1\,1\,\bar{2}\,0)$ . . . . (*M*)

63. The *Dihexagonal Pyramid* (Fig. 101) is contained by twenty-four equal scalene triangles. The principal axis lies

between the two twelve-sided solid angles, the lateral axes between alternate basal solid angles. Each face intercepts the principal and one of the lateral axes at the unit distances, and the other two axes at distances *h* and *k* (see Fig. 102), the ratio of which, $\frac{h}{k} = n$, is more than 1 and less than 2. If $n = 2$ the solid becomes an hexagonal pyramid of the second order. The plain angles formed by the basal edges are alternately larger and smaller than 150°, that is to say, the basal plane is not a regular dodecagon, in which *n* would have the irrational value 1·366.

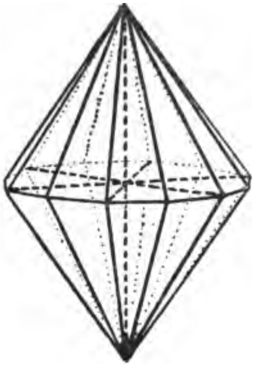


FIG. 101.

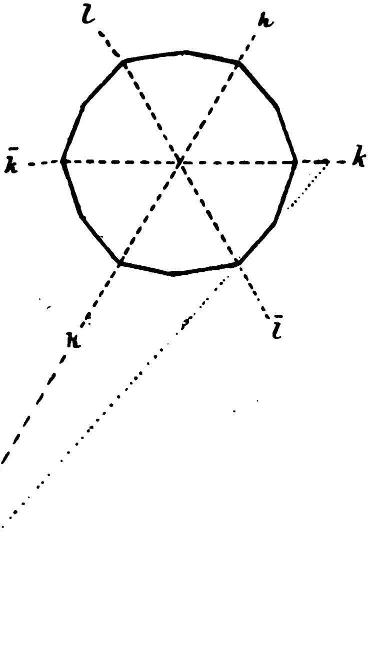


FIG. 102.

Symbols: $m\,P\,n$ (where $n = \frac{h}{k}$, and $m = \frac{h}{l}$ . . (N)

$a : n\,a : \frac{n}{n-1}\,a : m\,c$ . . . . (W)

$(h\,i\,k\,l)$. . . . . (M)

64. The *Dihexagonal Prism* (Fig. 103) is bound by twelve equal rectangles and two equal irregular dodecagons. The principal axis extends from centre to centre of the latter. The lateral axes lie between centres of alternate vertical edges. The dihedral angles over the vertical edges are alternately larger and smaller, as shown in Fig. 102.

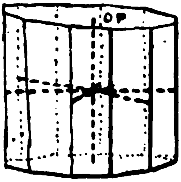


FIG. 103.

Symbols: $\infty P\,n$ . . . . (N)

$a : n\,a : \frac{n}{n-1}\,a : \infty\,c$ . . . . (W)

$(h\,i\,k\,O)$ . . . . (M)

65. The *Rhombohedron* is contained by six equal rhombs, opposite faces being parallel, and adjoining ones intersecting each other under an oblique angle. It is the holohedral form of the hexagonal pyramid, derived by the extension of alternate faces and the suppression of intermediate faces. The angles over the polar edges are the supplements of those over the middle edges. The six lateral solid angles and the two polar angles are respectively equal. The principal axis lies between the two last-mentioned solid angles; the lateral axes extend between the centres of opposite lateral edges. The polar angles are acute or obtuse according to the form of the original pyramid. In the acute rhombohedron (Fig. 104) the angles over the middle edges are greater

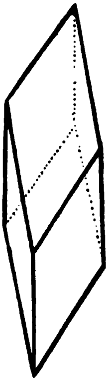


FIG. 104.

than 90°, in the obtuse rhombohedron (Fig. 105) they are less than 90°. In some minerals this dihedral angle differs but slightly from a right angle, and in such a case the rhombohedron approaches closely the form of a cube. The two sets of alternate faces of the hexagonal pyramid produce

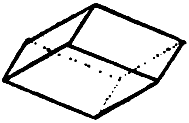


FIG. 105.

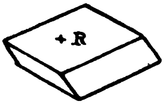


FIG. 106.

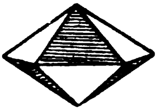


FIG. 107.

a positive and negative rhombohedron respectively. Thus the positive form (Fig. 106) is derived from the shaded faces of the hexagonal pyramid shown in Fig. 107, while the negative form (Fig. 108) is obtained from the white faces. The two forms are exactly alike, but their relative position varies by 60°, *i. e.* no face of the positive rhombohedron is parallel to a face in the negative rhombohedron. Obviously rhombohedra may be derived both from pyramids of the first order and those of the second order.

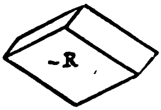


FIG. 108.

Symbols: $\frac{m\,P}{2}$ and $-\frac{m\,P}{2}$ . . . . (*N*)

$\pm \frac{1}{2}(a : a : \infty a : c)$ . . . . (*W*)

$\kappa(h\,O\,\bar{h}\,l) = \kappa(1\,0\,\bar{1}\,1)$, and $\kappa(O\,h\,\bar{h}\,l) =$
$\kappa(0\,1\,\bar{1}\,1)$ . . . . (*M*)

66. *Naumann's abbreviated notation.* The frequency with which hexagonal hemihedra occur in nature, and the consequent frequent occasion for the use of their symbols, induced Naumann to substitute the signs R and $-R$ for $\frac{m\,P}{2}$ and $-\frac{m\,P}{2}$ to indicate the positive and negative unit rhombohedra, and $m\,R$ and $-m\,R$ for their derivatives,

the coefficient *m* having a value intermediate between *O* and ∞. The basal pinacoid, hitherto noted as *O P*, in which $m = O$, is by this method indicated by *O R*, and the hexagonal prism of the first order, formerly ∞ *P*, now becomes ∞ *R*.

67. *Miller's hexagonal notation.* In his original system of rhombohedral notation Miller assumes three axes of reference, all three being inclined to each other. While the system is thus rendered "triclinic" it is not "asymmetric," since the axes are of equal length, and the inclination is the same in each of the axes. In the hexagonal prism the axes lie between alternate opposite solid angles, as shown in Fig. 109, the indices of the vertical faces are therefore $(1\ \bar{1}\ 0)$, etc., and those of the basal planes $(1\ 1\ 1)$ and $(\bar{1}\ \bar{1}\ \bar{1})$. In the rhombohedron the axes terminate in the centres of opposite rhombs, and are parallel to the polar edges. The symbols, like those of the cube, are therefore $(1\ 0\ 0)$, $(0\ 1\ 0)$, and $(0\ 0\ 1)$.

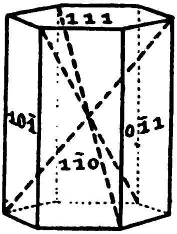


FIG. 109.

68. The *Scalenohedron* is contained by twelve equal scalene triangles. The principal axis connects the two six-sided solid angles, the lateral axes lie between the centres of opposite middle edges. The position of the latter is analogous to those of the rhombohedron. The scalenohedron is the hemihedral form of the dihexagonal pyramid, the faces corresponding with alternate pairs of faces in the holohedral form, as shown in Fig. 111. Two hemihedra may be produced from the same pyramid, distinguished as positive (Fig. 110) and negative (Fig. 112). They are exactly alike, but they occupy positions 60° or 180° apart. In accordance with the polar angle of the original pyramid the resulting scalenohedron is either acute or obtuse.

This form of hemihedrism is analogous to that in the tetragonal system, to indicate which the sign κ is used in

Miller's notation, although the crystal is really a parallel-faced one.

Symbols: $\pm \frac{m P n}{2}$ or $\pm m R n$ . . . . (*N*)

$\pm \frac{1}{2}\left[a : n a : \frac{n}{n-1} a : c\right]$ . . . . (*W*)

$\kappa\,(h\bar{i}\bar{k}l)$ and $\kappa\,(ik\bar{h}l)$, quadriaxial relation, $(h\,k\,l)$, triaxial relation. . . . . . (*M*)

69. The *Trigonal Trapezohedron* is the tetartohedral form of the dihexagonal pyramid, being derived from an extension

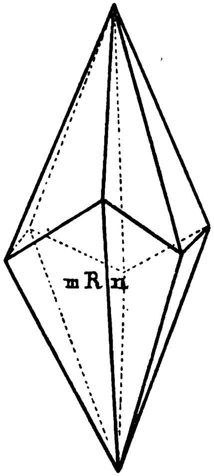


FIG. 110.

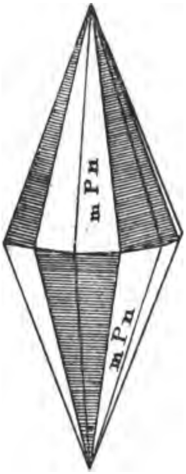


FIG. 111.

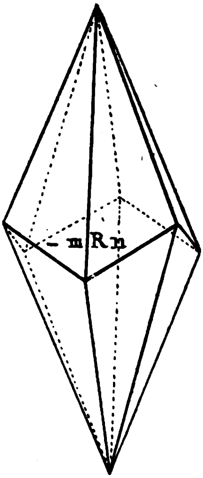


FIG. 112.

of alternate pairs of such faces of the scalenohedron as meet in the middle edges (see Fig. 114). In this way result two forms which are distinguished as right- and left-handed, and since the scalenohedron may be either positive or negative it is possible that four tetartohedra may originate from a single dihexagonal pyramid, viz. the right- and left-handed positive, and the right- and left-handed negative trapezohedra.

Thus if the scalenohedron shown in Fig. 114 be a positive one, the derivatives are right-handed positive (Fig. 115) and left-handed positive (Fig. 113), the faces of the latter corresponding with the shaded faces of Fig. 114.

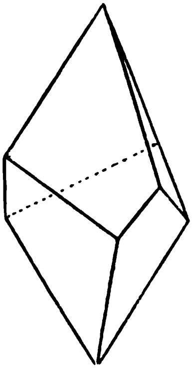


FIG. 113.

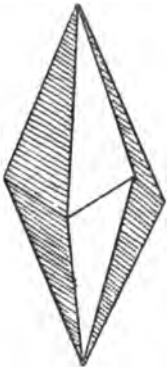


FIG. 114.

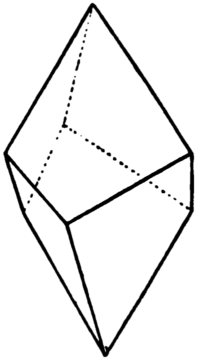


FIG. 115.

The trigonal trapezohedron is bound by six equal trapezoids. The six polar edges are of equal length; the lateral edges are alternately longer and shorter, the longer edges corresponding to the prolonged edges of the scalenohedron.

By a turn of the vertical axis to the extent of 60°, the right positive trapezohedron will completely occupy the space of the right negative form, and the left positive trapezohedron that of the left negative form; but the right positive trapezohedron cannot be brought, by a turn of the axis, to superpose the left positive form, nor the right negative trapezohedron to coincide with the position of the left negative form.

Symbols:

Right positive trigonal trapezohedron—

$$\frac{m\,P\,n}{4}\,r = \frac{m\,R\,n}{2}\,r \quad . \; . \; . \; . \; . \; . \; . \quad (N)$$

$$\kappa\,\tau\,(k\;i\;\bar{h}\;l) = \kappa\,(h\;k\;l) \quad . \; . \; . \; . \; . \quad (M)$$

Left positive trigonal trapezohedron—

$$\frac{m\,P\,n}{4}\,l = \frac{m\,R\,n}{2}\,l \quad . \; . \; . \; . \; . \; . \; . \; . \quad (N)$$

$$\kappa\,\tau\,(h\,\bar{\imath}\,\bar{k}\,l) = \kappa\,(h\,k\,\bar{l}) \quad . \; . \; . \; . \; . \; . \quad (M)$$

Right negative trigonal trapezohedron—

$$-\frac{m\,P\,n}{4}\,r = -\frac{m\,R\,n}{2}\,r \quad . \; . \; . \; . \; . \; . \quad (N)$$

$$\kappa\,\tau'(h\,\bar{k}\,\bar{\imath}\,l) = \kappa\,(h\,\bar{k}\,l) \quad . \; . \; . \; . \; . \; . \quad (M)$$

Left negative trigonal trapezohedron—

$$-\frac{m\,P\,n}{4}\,l = -\frac{m\,R\,n}{2}\,l \quad . \; . \; . \; . \; . \; . \quad (N)$$

$$\kappa\,\tau\,(k\,\bar{h}\,i\,l) = \kappa\,(\bar{h}\,k\,l) \quad . \; . \; . \; . \; . \; . \quad (M)$$

$$\tfrac{1}{4}\,(a : n\,a : \frac{n}{n-1}\,a : c) \quad . \; . \; . \; . \; . \; . \; . \quad (W)$$

70. *Holohedral hexagonal combinations.* Of the numerous minerals which crystallize in the hexagonal system the great bulk affects hemihedral, particularly rhombohedral, forms, while the proportion of those with undoubted holohedral crystallization is exceedingly small. Fig. 116 represents a crystal of beryl (p. 192), showing a combination of the hexagonal prism (∞ *P*), two proto-pyramids (*m P*) of different steepness ($o = 1\,0\,\bar{1}\,1$ and $p = 2\,0\,\bar{2}\,1$), the deutero-pyramid ($q = m\,P\,2$), the dihexagonal pyramid ($s = m\,P\,n$), and the basal plane ($c = O\,P$).

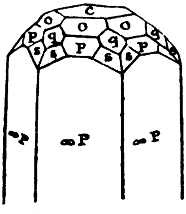


Fig. 116.

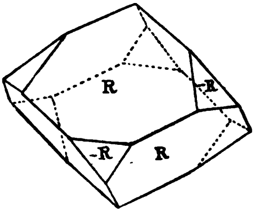


Fig. 117.

71. *Hemihedral hexagonal combinations.* The form represented by Fig. 117 is made up of the positive and negative

rhombohedra. Fig. 118 also shows a combination of two rhombohedra, but they are derived from pyramids of different steepness, *R* is the more acute, R^1 the more obtuse. The polar angles are replaced by basal planes (*O P*).

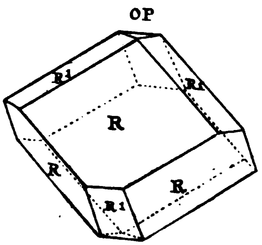


FIG. 118.

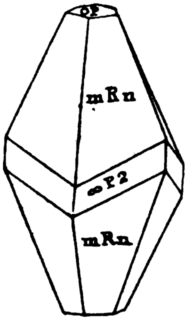


FIG. 119.

Fig. 119 shows the scalenohedron (*m R n*) truncated by basal planes (*O P*), and having the middle edges replaced by planes of the hexagonal prism of the second order (∞ *P* 2).

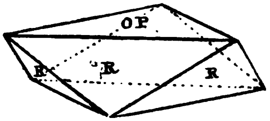


FIG. 120.

The tabular crystal (Fig. 120) represents the rhombohedron (*R*), having its polar angles truncated to such an extent as to give rise to two triangular basal planes (*O P*).

Fig. 121 is a form common in tourmaline (p. 216), contained by three alternate vertical planes of the hexagonal prism of the first order (∞ *P*), six faces of the dihexagonal prism (∞ *P n*), three adjoining pairs of vertical planes of the hexagonal prism of the second order (∞ *P* 2), and the rhombohedra (*R* and − *R*).

The next two figures (Figs. 122 and 123) represent common combination-crystals of quartz (p. 176), the former being a right-handed, the latter a left-handed, tetartohedron. The hexagonal prism (∞ *P*) and the positive and negative rhombohedra (R and $-R$) are common to both. The right positive trigonal trapezohedra $\left(\frac{m\,R\,n}{2}\,r\right)$, indicated by the letters x and z, lie to the right of the positive rhombohedron in the *right-handed* tetartohedron, while the left positive trigonal pyramids $\left(\frac{m\,R\,n}{2}\,l\right)$, indicated by the signs $\bar{x}$ and $\bar{z}$, lie to the left of the positive rhombohedron in the *left-handed* tetartohedron.

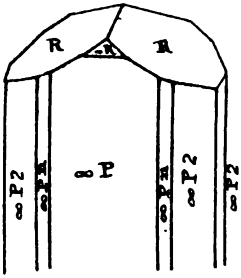


FIG. 121.

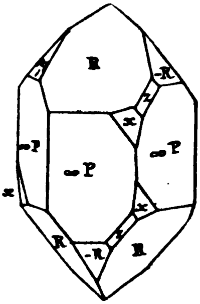


FIG. 122.

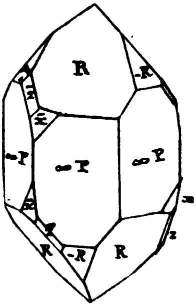


FIG. 123.

CHAPTER IX

COMPOUND CRYSTALS

72. *Parallel Grouping.* When two or more neighbouring masses of crystallizable matter are in the act of assuming crystal shape, the molecular grouping of one is liable to be influenced by the attractive and repelling forces operating in the other in such a way that the several crystals, now grown together, assume a determinate position in relation to each other. In the simplest case the more or less

imperfectly developed crystals arrange themselves in the direction of a single axis, in the manner indicated by Fig. 124. Another case is represented by Fig. 125, where the direction of growth is constant, that is to say, the crystals are grouped in parallel positions, but they do not lie in one continued axis.


FIG. 124.

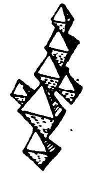


FIG. 125.

73. *Twin Structure.* A different case is presented when the orientation of the several crystals is wholly irregular, and there is no parallelism in their axes. Such crystals are called *twin crystals*, *maccles*, or *hemitropes*. If Fig. 127 represents two parallel octahedra which have one of their faces in common, and x y is a line perpendicular to this common face, then on turning the right-hand crystal half-way round the axis x y, the relative position of the two crystals will be that shown in Fig. 127, where the crystal axes intersect under an angle of 60°. This is an example of genuine twin structure, whereas the form shown in Fig. 126 is merely an example of parallel grouping.

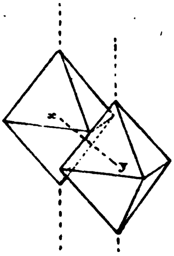


FIG. 126.

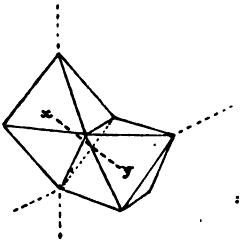


FIG. 127.

If an octahedron be bisected by a plane z, as indicated by Fig. 128, and the upper part of the crystal turned to the extent of 180° around the axis x y, which is normal to z, there results the twin form shown in Fig. 129. The plane *z* is called the ***twin plane***, and the axis *x y* the ***twin axis***. In the example under notice the twin plane is also the ***contact plane***, or ***plane of composition***, but this is not necessarily the case in twin crystals generally, as the positions of the two planes are wholly independent of each other. The contact plane is generally traceable by its perimeter, while the twin plane requires not seldom to be determined by calculation. In the majority of instances twin crystals are symmetrical in respect of a crystal plane, and only rarely is the twin axis parallel to a crystal edge. In no case is the plane of composition a plane of symmetry.

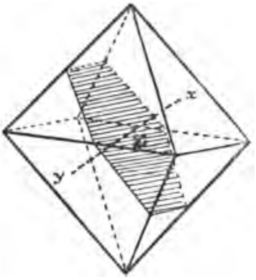


FIG. 128.

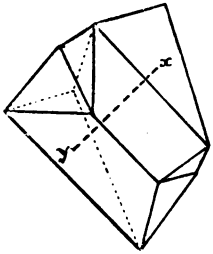


FIG. 129.

As a rule twin planes are parallel to the cleavage planes of a crystal, an indication that twinning has taken place in the direction of greatest resistance. The more pure and liquid a solution the less resistance it is likely to offer to the rotary motion of molecular aggregates, the more perfect will be the resulting crystal forms, and the less apt are twin crystals to be produced. On the other hand, the more viscous the solution or magma the greater resistance it presents to the gyration of solid particles, and the more readily will the crystals be subjected to torsion, *i. e.* affect twin structure.

Twin crystals, as a rule, exhibit alternating salient and reverting angles, as illustrated by the examples given in Figs. 127 and 129. There are nevertheless frequent exceptions to this rule. Thus in a combination of the cube and octahedron, such as is shown in Fig. 130, a revolution of one half of the crystal upon the other would produce the form Fig. 131, which contains no reverting angle. In that figure the faces marked by underlined symbols are those of that portion of the crystal which is assumed to have been turned from its normal position.

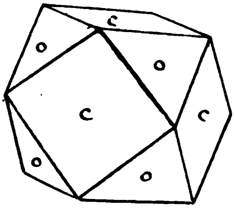


FIG. 130.

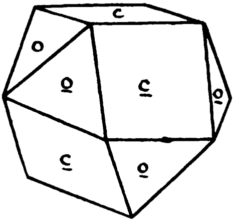


FIG. 131.

74. *Contact* and *Penetration Twins.* We have hitherto supposed the twin crystals to be made up of two complete crystals or of two portions of a complete crystal, and in the examples so far considered the twin crystals are separated by a single plane (the plane of composition). Twin crystals of such a structure are called *contact twins.* There is, however, another type of twinning which would result from one crystal penetrating another and then being subjected to

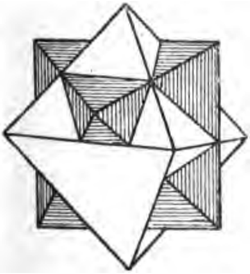


FIG. 132.

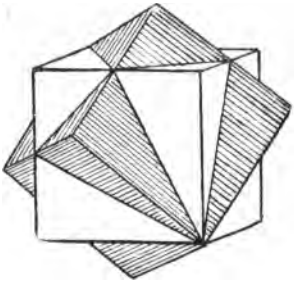


FIG. 133.

torsion. If the twin axis $x y$ of the octahedron (Fig. 127) were shortened, the mass of one crystal would for the most part replace that of the other, while the solid angles of one crystal would project beyond the faces of the other. The two crystals may be assumed to interpenetrate to such an extent that their centres are coincident, i. e. $x y = 0$. In that case the twin form will have the appearance shown in Fig. 132, where the faces of the one crystal are distinguished from the other by shading. Two cubes twinned in the same manner will produce the form illustrated by Fig. 133. Twin crystals which are thus intergrown, and present more than one contact plane, are called *penetration twins.*

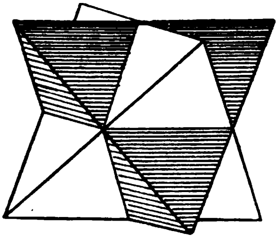


Fig. 134.

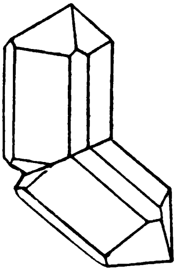


Fig. 135.

75. *Examples of Compound Crystals.* Fig. 134 represents a penetration twin composed of two regular tetrahedra in crossed positions. Fig. 135 is a contact twin of two tetragonal prisms; a form not uncommon in cassiterite. Fig. 136 shows a pair of parallel rhombic prisms connected by a narrow pinacoid which occupies a twin position on the face ∞P (1 1 0). This is also seen in the basal section (Fig. 137). Sometimes (as in the mineral aragonite, p. 160) this intermediate pinacoid is many times repeated (so-called twin lamellæ), and the crystal faces $\infty P \infty$ (0 1 0) and P (0 1 1) then present a series of fine lines parallel to the twinning plane. The example just given illustrates the most common mode of twinning in the rhombic system, viz. that in which

the axes of symmetry in the two crystals are parallel, and the twin plane is parallel to both. In the much rarer case where a pyramidal face is the twin plane, the two crystals have no parallel axes of symmetry. This mode of twinning is illustrated by Fig. 138, which represents a penetration twin crystal of staurolite (p. 220). It consists of two prisms with the faces ∞P (1 1 0), $\infty P \infty$ (0 1 0) and $O P$ (0 0 1). The twin plane, shown in a vertical position in the diagram, is coincident with the face of an acute pyramid, $m P$ (1 1 1).

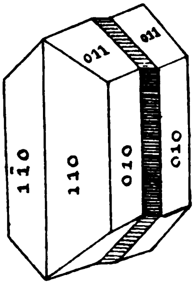


FIG. 136.

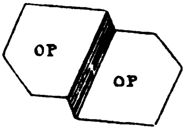


FIG. 137.

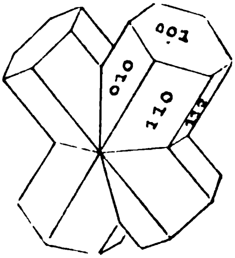


FIG. 138.

Fig. 139 represents two monoclinic prisms of the form shown in Fig. 88, with the faces ∞P and $\infty \bar{P} \infty$, and planes of the hemi-pyramid $m P$. The twin plane, indicated by a dotted line, is parallel to the orthopinacoid. This is a form of contact twin frequently seen in gypsum (p. 165).

Figs. 141 and 142 represent compound crystals derived from the form illustrated by Fig. 140, which like that referring to the last example shows a combination of the clinorhombic prism and hemi-pyramid. The crystals, though partially interpenetrating, are contact twins, the contact plane being parallel to the clinopinacoid. They are distinguished as right-handed twin (Fig. 142) and left-handed twin (Fig. 141), according to the direction in which one individual crystal has been turned upon the other. The twin plane is the orthopinacoid. Fig. 143 is a section in the plane of composition; Fig. 144 a transverse section in which the plane of composition is indicated by the middle vertical line. This form, known as the Carlsbad type of twinning, occurs frequently in orthoclase (p. 207).

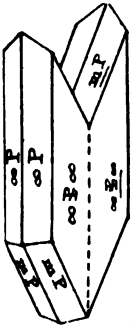


FIG. 139.

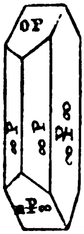


FIG. 140.

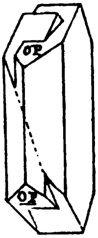


FIG. 141.

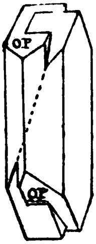


FIG. 142.

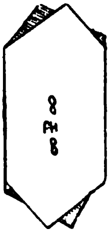


FIG. 143.

Fig. 145 represents a crystal similar to that shown in Fig. 140, with, however, a broader base. Twinning on a plane parallel to the clinodome, indicated by a dotted line, produces the crystal Fig. 146. This is also a form not uncommonly affected by orthoclase, and known as the Baveno type of twinning.

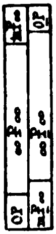


FIG. 144.

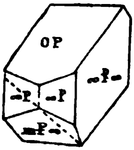


FIG. 145.

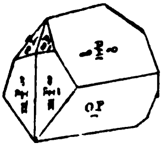


FIG. 146.

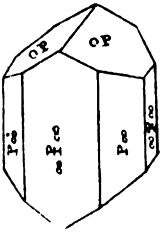


FIG. 147.

The combination Fig. 147 twinned on the orthopinacoid produces the form Fig. 148, commonly occurring in augite (p. 188). Fig. 149 is a contact twin in which the individual is a combination of the triclinic prism and hemi-pyramids.

The composition plane is parallel to the brachypinacoid, and is indicated in the diagram by the medial vertical line. This form is characteristic of the mineral albite (p. 210), and is accordingly designated as the "albite type" of twinning. The twin growth is often many times repeated in the same crystal by the intercalation of twin lamellæ, thereby producing *polysynthetic* twinning, which displays itself by a series of fine parallel lines on the basal cleavage planes. A trilling of this kind is shown in Fig. 150, where

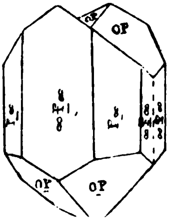


FIG. 148.

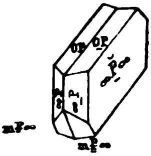


FIG. 149.

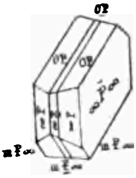


FIG. 150.

the two parallel medial lines indicate the composition planes. The central lamella occupies a twin position in regard to either of the individuals on the right and left, which are parallel.

Fig. 151 represents a contact twin, made up of two halves

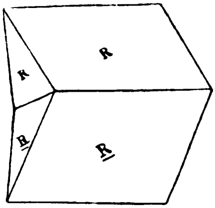


FIG. 151.

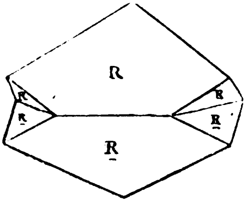


FIG. 152.

of a rhombohedron, the twin plane being a face of the rhombohedron.

Fig. 152 is also a crystal composed of two parts of a rhombohedron, the twin plane being parallel to the base.

Fig. 153 similarly shows a compound crystal of two scalenohedra in which the plane of composition is parallel to the base.

If two hexagonal crystals of the form shown in Figs. 122 and 123, but of the same denomination, *i. e.* either both right-handed or both left-handed, are so intergrown that the faces of the positive rhombohedron of the one individual are parallel to the faces of the negative rhombohedron of the other, there results a compound crystal of the form shown in Fig. 154, which might at first sight be mistaken for a simple crystal. It will be observed, however, as an indication of twinning that the rhombohedral faces of one individual are less brilliant than those of the other, as shown by shading in the diagram. Moreover, in the simple crystal the faces of the trapezohedron *x* and the trigonal pyramid *z* can only occur at alternate basal angles (see Figs. 122 and 123), while in the compound crystal they occur at neighbouring angles (see Fig. 154), and may indeed be present at all the six basal angles.

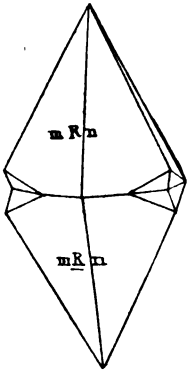


Fig. 153.

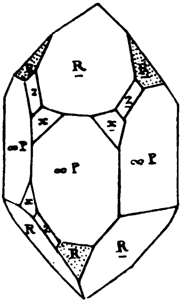


Fig. 154.

CHAPTER X

ABNORMAL CONDITIONS OF CRYSTALLIZATION

76. *Imperfection of crystal forms.* It has been pointed out (par. 6, *ante*) that crystals are but rarely developed uniformly in every direction, and hence as a rule present forms which deviate more or less widely from the regular geometrical outlines; and further (in the last chapter), that the symmetry of crystals is liable to be materially affected by twin structure. Apart from such general distortion the individual faces of a crystal often exhibit marked imperfections, and instead of being mathematically true planes, are warped, curved, striated, grooved, hollowed, or roughened. Such irregular surfaces point to interruptions in the growth of the crystal, to partial erosion, or to secondary deposition of mineral matter upon an existing crystal. Bent and curved crystals may also arise from mechanical disturbance in the matrix during separation, as for instance augite in basalt lava.

77. *Isomorphism.* In the chemical constitution of a mineral substance the molecules of different elements arrange themselves in different manner. In some elements, or groups of elements, this difference is less marked than in others, and in some cases there obtains a similarity of molecular disposition which enables the molecules of one element to replace an equal number of molecules of another, without notably interfering with the crystal form of the substance in the composition of which they enter. Thus in garnet (p. 195) Fe_2O_3 is frequently substituted for Al_2O_3, and *vice versâ*, the internal re-arrangement of the molecules not, however, affecting the form of the mineral. Similarly in pyroxene and amphibole the mutual exchange of Ca and Mg, or of Fe and Mn, is unaccompanied by any morphological change. Elements or compounds which crystal-

lize in the same form, the chemical relations of which are of the same order, and which are capable of replacing each other wholly, or in part, are said to be *isomorphous.* Following are some examples of mineralogically important groups of isomorphous substances. Phosphoric and arsenic acids, *e. g.* in the hexagonal minerals apatite, pyromorphite, and mimetite; the sulphates of calcium, barium, and strontium, as present in the minerals anhydrite, barite, and celestite; the chlorides of sodium, potassium, and silver, as in halite, sylvite, and cerargyrite; the carbonates of calcium, magnesium, iron, manganese, and zinc, as present in the undermentioned group of rhombohedral minerals—

Calcite	105° 05′
Dolomite	105° 30′
Rhodochrosite	106° 10′
Siderite	106° 45′
Magnesite	107° 12′
Smithsonite	107° 40′

The angles given are those of the terminal faces of the rhombohedra, and show that although the crystal forms are not absolutely identical the variation is but slight. Another isomorphous group is that including the carbonates of calcium, strontium, lead, and barium in the rhombic minerals—

Aragonite	116° 16′
Strontianite	117° 0′
Cerussite	117° 40′
Witherite	118° 30′

The dimensions here given are those of the obtuse angle over the side faces of the rhombic prism.

In some few cases of isomorphism there is no apparent similarity in chemical composition, as for instance in the rhombohedral minerals quartz and chabazite, and in the holohedral hexagonal species beryl, apatite, and nephelite.

78. *Heteromorphism.* A mineral species crystallizes as a rule in one radical form only; there may be numerous varieties of that form, but there always exists between them a close geometrical connection. The type form is characteristic of the species in every locality, and whatever its mode of occurrence. To this general rule there are, however, some exceptions, since it is found in certain cases that a substance of definite chemical composition may appear in two or more crystallographically distinct forms, the difference in form being usually accompanied by greater or lesser differences in physical properties. Such substances are called *heteromorphous.* Thus native sulphur crystallizes in the rhombic system, while artificially produced "flowers of sulphur" are made up of tetragonal prisms. A mineral affecting two distinct crystal forms is said to be *dimorphous.* Thus calcium carbonate crystallizes rhombohedral as calcite, which has a specific gravity of 2·7, and trimetric as aragonite with the greater density of 2·9. Silica occurs tetartohedral as quartz with a specific gravity of 2·7, and holohedral as tridymite with a gravity of 2·3. Sulphide of iron appears in cubical crystals as pyrite, and in rhombic crystals as marcasite. Substances which are capable of assuming three distinct crystal forms are called *trimorphous.* In some substances this capacity for heteromorphism extends yet further, and to such cases the term *polymorphism* (or pleomorphism) is applied. Titanium dioxide, composing the minerals brookite, rutile, and octahedrite, affords an example of trimorphism. Brookite crystallizes rhombic, rutile in tetragonal prisms, and octahedrite in tetragonal pyramids. Although the last-mentioned two forms belong to the same crystal system they are genetically distinct, and the axial relations in each case definite and constant.

79. *Allotropy.* In some substances, chemically alike but morphologically distinct, the physical properties contrast

more strongly than is usual in ordinary heteromorphous compounds. Thus the element carbon constitutes the three radically distinct mineral species *diamond*, which crystallizes octahedral, is limpid and of supreme hardness; *graphite*, which occurs in thin hexagonal prisms, is opaque with metallic lustre and exceedingly soft; and *anthracite*, an amorphous substance, black, opaque, stony, and of medium hardness. Such substances are said to be *allotropic*.

Allotropic minerals, in common with heteromorphous minerals in general, though of identical composition, are properly classed as separate species, by reason of the differences not only in physical properties but in the conditions under which they have, or are assumed to have, been produced.

80. *Pseudomorphism*. A mineral once formed does not maintain its normal condition indefinitely; on the contrary during the progress of change to which the inorganic no less than the organic world is subject, the destruction of existing forms leads to new combinations, and the generation of new bodies. The causes of the alteration of minerals must be looked for in the first place to meteoric agency, *i. e.* atmospheric air and water, oxygen, carbonic acid, and ammonia, variations in temperature, light and electricity; in the next place to solutions resulting from the action of air and moisture on minerals, and solutions containing organic acids; and finally to acids and vapours usually derived from deep-seated sources, particularly HCl, SO_2, and $FeCl$. In all cases the energy of this action is enhanced by the aid of heat and aqueous vapour, as in the presence of thermal waters, or during eruption of heated rock-matter. Under favourable conditions both the form and substance of the mineral are altered, that is to say, the original mineral is wholly replaced by new matter of different composition, and capable of crystallizing in a form proper to that composition. In some cases, however, the transformation takes place in the substance alone, without interfering with the

outward form of the original mineral. Natural substances which thus have the composition of one mineral and the crystal form of another are termed *pseudomorphs*. Pseudomorphism has probably in all cases been brought about in the humid way, *i. e.* by precipitation from solutions, but the exact processes involved—complicated and protracted as they, no doubt, in most instances were—do not always admit of ready interpretation. Some of the conditions under which the production of pseudomorphs appears to have most commonly taken place may here be briefly explained.

(*a*) Pseudomorphs arising from a *loss of constituents*. An example is afforded by the species anhydrite ($CaSO_4$), which properly crystallizes in rhombic forms, occurring in monoclinic pseudomorphs after gypsum ($CaSO_4 + 2H_2O$). The change has been effected by the latter having parted with its moisture. Thus also argentite (Ag_2S) is found occasionally in the rhombic form of stephanite ($5\,Ag_2S.\,Sb_2S_3$), the transmutation being due to the removal from the latter of sulphide of antimony.

(*b*) Pseudomorphs arising from *access of constituents*. Argentite by taking up sulphide of antimony is changed into the rhombohedral species pyrargyrite ($3Ag_2S.\ Sb_2S_3$) without divesting itself of its isometric form. Galena (PbS), by gain of oxygen, becomes anglesite ($PbSO_4$). Hematite, by taking up water, is converted into limonite.

(*c*) Pseudomorphs arising from *partial exchange of constituents*. Pyrite (FeS_2), by loss of sulphur and access of oxygen and water, is changed into limonite ($2Fe_2O_3 + 3H_2O$). Witherite ($BaCO_3$), on parting with its carbon dioxide and taking up sulphuric acid, has the constitution of barite ($BaSO_4$).

(*d*) Pseudomorphs by *substitution* arise from the total replacement of the original substance of a crystal by new matter, the change, however, involving no chemical reaction whatever between the two substances. Thus quartz occurs pseudomorphous after fluorite; cassiterite after orthoclase.

When organic matter is similarly replaced, the new material becomes the petrifying medium of organic remains. Thus in silicified wood, and wood opal, the original wood tissue is replaced by quartz. In Cornwall deer's antlers have been found, the horny substance of which has been converted into cassiterite. In the tertiary strata of Southern Victoria the whorls of cerithium have been observed to consist of pyrite.

Frequently pseudomorphous crystals result from several consecutive processes, such as substitution following upon an exchange of constituents. Of this kind are the pseudomorphs of calcite after cubical galena, the latter mineral having been in the first stage altered to cerussite through loss of sulphur and access of carbon dioxide, while in the next stage the carbonate of lead was wholly removed, and its place taken by carbonate of lime.

(*e*) Pseudomorphs by *paramorphism.* Here a change of internal structure is effected while crystal form as well as composition remain unaltered. Obviously this kind of pseudomorphism can only take place in dimorphous minerals, *e. g.* calcite after aragonite, pyrite after marcasite, amorphous silica after quartz, etc.

(*f*) Pseudomorphs by *investment* (incrustation). If a mineral substance is evenly deposited upon the pre-existing crystal of another mineral, and the latter is at the same time, or subsequently, dissolved and removed, the remaining incrustation will present the outward form, although somewhat enlarged, of the original crystal. Thus we not seldom meet with hollow crystals of quartz that have been built upon fluorite, of dolomite upon rock-salt, and of siderite upon calcite, the minerals fluorite, halite, and siderite being particularly liable to attack by acidulated waters having been removed in solution.

(*g*) Pseudomorphs by *infiltration* (casts). A crystal which is enveloped by another mineral substance will on its removal by solution leave its form within the surrounding material. If now some new compound find its way into the cavity a cast of the original crystal will be formed. In this way pyrite occurs pseudomorphous after halite, calcite in the form of barite, chrysocolla in that of cerussite.

The combined processes of infiltration and incrustation are productive of forms the origin of which is sometimes difficult to trace. The following is an instance of complex pseudomorphism. In the diagram (Fig. 155), *c* represents a crystal of cerussite, which has received a thin crust of galena. On this was subsequently deposited a layer of calcite (*b*). Ultimately the carbonate of lead was entirely carried away in solution, and the vacant space *c* filled with carbonate of lime. We have here clearly an investment pseudomorph of galena after cerussite, the external calcite being a secondary incrustation, and the inner mass merely a cast.

FIG. 155.

The resemblance of a pseudomorphous crystal to its prototype is the closer, the more nearly alike the densities of the original and derivative substances are. Thus in pseudomorphs of calcite after quartz, two minerals which have nearly the same specific gravity, the angles, edges, and faces are as a rule sharply defined. In general, however, the densities of the two substances are more or less at variance. When the substance of the pseudomorph is of lesser density than that of the original it will be apt to expand beyond the bounds of the crystal. Thus in pseudomorphs of gypsum (sp. gr. 2·32) after anhydrite (sp. gr. 2·98), the expansion superinduced by hydration amounts to 1·6 of the original volume, and the crystals are in consequence greatly swollen and roughened. On the other hand, a diminution in volume is attended by imperfect filling of the space occupied by the original substance. Thus paramorphs of aragonite (sp. gr. 2·9) after calcite (sp. gr. 2·7) usually present vesicular and drusy cavities. In both cases the original crystal form will be considerably defaced. As a rule, moreover, the internal structure, such as cleavage, and optical properties such as lustre, of the original mineral are lost in the pseudomorph, whatever its derivation has been.

CHAPTER XI

PHYSICAL PROPERTIES

81. *Crystalline Structure.* Under ordinary circumstances the disposition of the molecules of a crystallizable substance is governed by the law of crystallization. Extraneous agencies, such as excessive pressure or abnormal changes of temperature, may, however, bring about a mutual interference of the molecules, when the supervening structure, though still presenting some degree of regularity, does no longer accord with any recognized geometrical system of crystallization. Such a molecular arrangement is defined as *crystalline structure,* as may be observed in the argentiferous variety of galena known as "steel ore," in Carrara marble, and in artificial substances such as antimony regulus and sugar-candy.

82. *Amorphous Structure.* Minerals which are neither crystallized nor possessed of crystalline structure are called *amorphous.* Any substance, otherwise crystallizable, may, nevertheless, assume an amorphous form if the requisite conditions for crystallization are wanting. There are some mineral bodies, however, that have never been observed in a crystallized or crystalline form, and regarding these it is safe to assume that they are heterogeneous compounds and not distinct mineral species, *e.g.* flint, wad, etc. Amorphous minerals occurring in bodies of considerable bulk are called *massive.* If the mass is made up of particles of approximately uniform size it is *granular;* when it is so dense that the

individual grains are not distinguishable it is *compact.* A large-grained, soft mineral the grains of which have but a slight coherence is said to be earthy, *e.g.* chalk; when of finer grain and in a state of powder it is *pulverulent* or even *impalpable*, *e.g.* the oxides of the metals tungsten, bismuth, molybdenum. A mineral is *porous* when it is traversed by numerous, exceedingly minute, open spaces between its component particles; *cavernous* when the cavities are of large size. Porous structure may be looked upon as a primary property; cavernous structure results from corrosion, and is therefore of secondary origin.

83. *Imitative forms.* In many minerals there is a tendency for the layers of growth to arrange themselves concentrically, thereby imparting to the mass an externally rounded shape, while its internal structure is more or less distinctly crystalline. Such aggregates are apt to bear an artificial aspect or resemble organic bodies, and hence are called *imitative forms.* The following are examples of frequent occurrence.

Concretions, *nodules*, consist of mineral matter which has separated from a compound or mixture, and been deposited in successive layers round a nucleus. They are usually composed of material which is denser and harder than the gangue from which it has separated. The carbonates of lime, magnesia, and iron, hydrated oxide of iron, and the colloid varieties of silica are among the most common substances to affect concretionary structure. *Reniform* is a term applied to nodular concretions of kidney shape; in confined situations reniform bodies are liable to spread out and become flattened. *Pisolitic* refers to rounded concretions of the size of peas; the individuals are always detached. A mineral is *globular* when it has the form of a more or less perfect sphere, one portion being, however, always attached to the support on which it has been deposited.

The term *oolitic* is used to describe clusters, resembling fish ova, of minute concretions of spherical or oval shape, the individuals being attached to each other with or without a cementing medium. *Botryoidal*, resembling a bunch of grapes, refers to an aggregation of semi-globular concretions closely bound to each other and to a mutual support. *Mammillary* forms resemble the last-mentioned, but the hemispherical protuberances are of larger size, generally in clusters, and always attached to a support. *Stalactitic*, resembling an icicle, implies a conical shape, a concentric structure, and a pendant position during growth. *Stalagmitic* refers to flattened cones, built up in successive layers, which thin out towards the edges, and are reposing upon a support. *Coralloid* forms are made up of branching and intertwining stems like coral, frequently seen in calcsinter and aragonite. The term *filiform* describes slender, interlacing threads like wire, not uncommon in native silver and native gold. *Mossiform*, *arboriform:* the aggregates ramify from a common stem in the manner of plants, a habit affected by most malleable metals. *Dendritic*, resembling the outlines of cryptogamic plants; the mineral has been deposited in thin coatings upon capillary joint planes of another mineral or rock, *e.g.* the hydrated oxides of manganese and iron. Rounded masses of gold found in detrital deposits are called *nuggets*. Particles of native gold of the size of grains of shot are said to be *shotty*.

84. *Other aggregates.* A mineral is described as *tabular* when it breaks up into broad parallel plates of moderate thickness, *e.g.* barite. *Lamellar*, the individual plates are somewhat thinner, *e.g.* albite. *Foliated*, the plates are thin, warped, leaf-like, and easily separable, *e.g.* talc. *Micaceous*, the easily separable plates are extremely thin but straight, *e.g.* mica. *Scaly*, the mineral occurs in detached plates of minute dimensions and not readily further divisible. *Columnar* structure is produced by the parallel grouping of numerous elongated prisms, closely joined together, *e.g.* tourmaline. When these prisms are exceedingly slender the mineral becomes *fibrous*, *e.g.* hornblende. If the fibres

run in diverse directions, so as to produce a matted structure, the mineral is said to be *reticulated*, *e.g.* galena.

Prisms, particularly those belonging to the rhombic system, are frequently found to be abnormally elongated and tapering to a needle-point; they are hence called *acicular* crystals, and occur usually in bundles, in which each individual preserves, however, its individuality, *e.g.* aragonite. In a still more attenuated form the prismatic crystals become hair-like or *capillary*, *e.g.* jamesonite. Crystal aggregates are *divergent* when they present a fan-like shape, *e.g.* tourmaline. When the divergence proceeds regularly all round a central axis it produces a *radiating* structure, *e.g.* vivianite. A mineral is said to be *stellate* when the bundles of radiating crystals, usually of minute size, are arranged in flat star-shaped aggregates, *e.g.* molybdite. A *druse* or *geode* is a cavity in a mineral or rock lined with crystals or crystalline aggregates of another mineral. In an *amygdaloid* the cavities, which are usually of small dimensions, are completely filled with amorphous mineral matter. A crystal on which smaller crystals or crystalline aggregates of the same or a different mineral are deposited is said to be *invested.* An *encrusting* mineral is in the form of a thin coating upon another mineral or a rock, and is generally amorphous or of imitative shape. Crystals or grains of a mineral which are wholly confined by another mineral or rock are *embedded;* if the crystals are confined only at their bases they are *implanted.* A mineral occurring in numerous minute grains scattered through a gangue is said to *disseminated.* When a compact rock contains isolated crystals of one or more minerals the constituents of which are also elementary constituents of the bounding rock, the latter is called a *porphyry.* Thus felsite, which is an intimate mixture of quartz and orthoclase, often contains well-defined crystals of one or both of these minerals, and is then termed felsite porphyry, while the quartz and felspar crystals are said to be *porphyritically enclosed* in the felsite.

Similarly, when stating that garnet occurs porphyritically in mica schist, it is implied that the mineral has been generated by the partial separation of silica, alumina, iron, etc., from the body of the rock itself, and not by the introduction of these constituents from without.

85. *Cohesion.* The resistance which a substance offers to rupture or abrasion is termed its *cohesion.* In some substances the molecules that have been displaced by an extraneous force insufficient to cause absolute rupture are capable of resuming their original position when that force has been removed. This property is called *elasticity.* Thus a bent plate of mica will on release of the pressure spring back into its original position, similarly to a strip of whalebone. Substances which, like beeswax, yield to force without breaking, but are incapable of resuming their original position, are called *flexible*, *e.g.* talc, kaolin.

86. *Cleavage.* In most crystals and in many crystalline aggregates the molecules are arranged in planes of least coherence, along which the substance splits more readily than in any other direction. This property of a mineral of breaking along defined parallel planes is called its *cleavage*, and the degree to which it is developed in the mineral is expressed by such terms as *highly perfect*, *perfect*, *distinct*, *imperfect*, *interrupted*, and *indistinct* cleavage. The cleavage planes are usually parallel to one or more of the faces of the primary crystal, and their direction is described in terms of these faces. Thus mica has a single cleavage parallel to the base of a prism, and hence is said to be possessed of a *basal* cleavage. Galena cleaves in three directions, viz. those parallel to the faces of the cube; it has a *cubical* cleavage. Similarly we speak of *octahedral* cleavage, *e.g.* in diamond; *dodecahedral* cleavage, *e.g.* in sphalerite; *rhombohedral* cleavage, *e.g.* in calcite. The mineral gypsum has one highly perfect clinodiagonal cleavage, another less perfect orthodiagonal cleavage, and a third imperfect pyramidal cleavage.

87. *Fracture.* When a mineral is broken in a direction other than that of the cleavage, the appearance of the fresh faces is called its *fracture.* The fracture is said to be *even* or *smooth* when the surface approaches that of a true plane; *uneven* or *earthy* when the faces are warped, interrupted, and roughened. The fracture is *conchoidal* when the break presents a shell-like, convex, or concave surface. Most fibrous minerals break with a *splintery* fracture; malleable metals with a *hackly* fracture.

88. *Hardness.* That modification of cohesive force which tends to resist abrasion is called *hardness.* This property varies considerably in different minerals, while it is constant in the same species, and hence constitutes one of the most important physical characters of a mineral. To express the degree of hardness of a mineral it is compared with certain type-minerals the relative hardness of which is represented by numerical characters ranging from 1 to 10. The type-minerals, originally proposed by Mohs, and now generally spoken of as constituting "Mohs' scale," are the following—

Talc	1	Orthoclase . .	6
Gypsum . . .	2	Quartz	7
Calcite . . .	3	Topaz	8
Fluorite . . .	4	Corundum . .	9
Apatite . . .	5	Diamond . . .	10

The pressure of a knife-blade in a practised hand suffices as a rule to determine the hardness of minerals ranging from 3 to 6. Minerals with a hardness of 1 and 2 can be scratched with the finger-nail. Those of a hardness greater than 6 require the aid of specimens of the minerals mentioned in the table of reference. A mineral that can be scratched by one of the test specimens, and in its turn scratches the type-mineral next below in the scale, has obviously a hardness intermediate between the two. Thus beryl scratches quartz (7), while it is scratched by topaz (8);

its hardness may therefore be set down at 7·5. In examining the hardness of an easily-cleaving mineral or of a crystal the faces of which are striated, the scratch should be made in a direction parallel to the cleavage planes or lines of striations.

89. *Tenacity.* In different minerals the fragments detached either by means of a cutting instrument or the pressure of a pestle will be found to present different forms. When the particles separate as a powder or in small grains the mineral is described as *brittle*, *e.g.* quartz, cerussite, pyrite. Minerals which under pressure may be reduced to powder, yet permit of fragments being cut off with a knife, are said to be *sectile*, *e.g.* talc, cerargyrite, calcocite. A mineral which is sectile under the knife and at the same time may be flattened out under the pestle or hammer, but which cannot be pulverized under pressure, is said to be *malleable*, *e.g.* most native metals.

The properties of cleavage, frangibility, hardness, and tenacity of a mineral bear as a rule no relation to each other. Thus diamond is at once the hardest substance known, highly brittle, and one of the most readily cleavable minerals; while in serpentine moderate hardness and indistinct cleavage are associated with extreme toughness.

90. *Density.* The density of a substance is expressed by the weight of a unit quantity of that substance; *e.g.* a cube inch of gold weighs 11 oz., a cube inch of quartz weighs 1·5 oz. By specific gravity we understand the ratio which the density of a substance bears to the density of water. A cube inch of water weighs 0·577 oz., and its specific gravity being taken as 1, the specific gravity of gold is $\frac{11}{0{\cdot}577} = 19$, and that of quartz $\frac{1{\cdot}5}{0{\cdot}577} = 2{\cdot}6$.

To determine the specific gravity of a mineral three observations of weight are requisite. In the first place the fragment of mineral is accurately weighed in the balance;

it is next suspended by a thread of silk, or better by a piece of fine platinum wire, from a hook beneath one of the pans of the balance and again weighed. Finally, while so suspended it is allowed to sink into a vessel containing distilled water and weighed. The difference between the second and third weights represents the weight of the displaced water. By dividing the absolute weight of the sample, observed in the first operation, by the weight of an equal volume of water we obtain the specific gravity of the mineral. *Example.* To find the density of albite. A fragment of the mineral was found to weigh 560 milligrams, and with the attached platinum wire 570 milligrams. When suspended in water it weighed 366 milligrams. The weight of the displaced water is, therefore, $579 - 366 = 213$, and the specific gravity $= \frac{560}{213} = 2{\cdot}629$.

Another method for the determination of the density of minerals is that by means of a specific gravity bottle or pygnometer. This is a small flask with a ground and finely perforated glass stopper which allows superfluous water to overflow. Having ascertained consecutively the absolute weight of the sample, $= w$, and the weight of the bottle filled with distilled water, $= u$, the sample is placed within the bottle and the weight of the whole apparatus taken, $= v$. The weight of displaced water is then $w + u - v$, and the specific gravity $G = \frac{w}{w + u - v}$. In all cases where the mineral is vesicular, porous or pulverulent, the pygnometer should be employed, the mineral being introduced in small fragments or even in the state of powder. In order to prevent the access of air bubbles it is advisable to moisten the fragments by means of a soft camel-hair brush before dropping them into the flask. It may even be necessary to resort to boiling the water containing the sample until all the air has been expelled.

For rapidly ascertaining the proximate relative density of mixed materials, or for separating the several constituents of a mixture in the form of loose grains, no better means can be employed than the use of a standard solution, such as Sonstadt's Solution, which is made up of 4 parts of potassium iodide and 5 parts of mercuric iodide dissolved in water. When concentrated the solution has a density of 3·1. Amphiboles, pyroxenes, garnets, etc., sink in the liquid; quartz, felspars, zeolites, etc., float; while tourmaline, apatite, fluorite, etc., remain suspended in it.

91. *Electricity.* Some minerals become electric by pressure, *e.g.* calcite, topaz, fluorite, etc.; others by friction, *e.g.* topaz, diamond, sphalerite. In others, again, electricity is developed by heat, *e.g.* tourmaline, calamine, prehnite, boracite, etc.; these are said to be pyro-electric. Electricity, by whatever means excited, can be best detected by observing the deflection of a galvanometer. In most cases it will, however, suffice to hold the electric mineral within a short distance of some particles of a light substance, such as cork dust, and note the alternate attraction and repulsion of these particles.

92. *Magnetism.* There are but few minerals which are naturally magnetic; those of most importance are native iron, magnetite, pyrrhotite, and some varieties of chromite, iserite, and native platinum. The two first-named are frequently polar-magnetic. Many ferriferous and niccoliferous minerals, which are in their normal condition non-magnetic, become magnetic through oxidation, particularly by heating. Magnetism is detected by means of an artificial magnet, such as the magnetized blade of a pocket-knife. In addition a magnetic needle that can be balanced on a pivot is indispensable; an ordinary pocket compass will serve the purpose.

CHAPTER XII

OPTICAL CHARACTERS

93. *Refraction.* In a homogeneous medium a beam of light is transmitted in an unbroken straight line. On entering a medium of different density its direction is changed, *i. e.* it is *refracted.* If the new medium be denser than the first the beam is refracted *towards* the perpendicular; if it be rarer it is refracted *away from* the perpendicular. Thus the ray *a o* (Fig. 156) passing through air will in its passage through glass be deflected to *o e*. The angle *c o a* is the angle of incidence (*i*); angle *d o e* is the angle of refraction (*r*), which, in this case, is smaller than *i*. For any two given media there is a fixed ratio between the sine of the angle of incidence and the sine of the angle of refraction (in the present case between *o g* and *o f*), and this ratio, usually expressed by *n*, is called the *index* of refraction, $n = \frac{\text{sine } i}{\text{sine } r}$. As a rule *i* refers to air. The indices of refraction of some of the most pellucid substances are as follows—

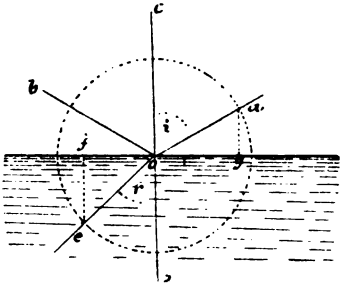


FIG. 156.

Water	1·336
Quartz	1·548
Glass	1·639
Calcite	1·654
Sapphire	1·794
Garnet	1·815
Sphalerite	2·260
Diamond	2·470

If i is $= \sigma$, sine $i = \sigma$ and $r = \sigma$, *i. e.* a beam of light falling perpendicularly upon the plane of contact between two media suffers no refraction.

If $i = 90^\circ$, sine $i = 1$; $n = \frac{1}{\text{sine } r}$, hence sine $r = \frac{1}{n}$.

Thus for water sine $r = \frac{1}{1{\cdot}336}$; $r = 48^\circ\ 35'$;

„ flint glass „ „ $= \frac{1}{1{\cdot}639}$; $r = 37^\circ\ 36'$;

„ diamond „ „ $= \frac{1}{2{\cdot}47}$; $r = 23^\circ\ 53'$.

This angle is called the *limiting* or *critical* angle. Accordingly if a beam of light passing through water in the direction from e to o strike the surface at an angle r greater than 48° 35′, it undergoes no refraction but is reflected towards b. Similarly a beam of light falling upon diamond at an inclination which demands a refractive angle greater than 23° 53′ will be totally reflected. Light so reflected produces what is called *brilliancy* in a substance.

94. *Reflection.* Only a part of the beam $a\ o$ (Fig. 156) undergoes refraction; another part is reflected in the direction $o\ b$. The angle of incidence is equal to the angle of reflection, *i. e.* $\wedge\ c\,o\,a = \wedge\ c\,o\,b$. The rays of incidence, refraction, and reflection *lie in the same plane.*

95. *Dispersion.* When a beam of light is made to pass through a glass prism its component parts are refracted to a different extent. That part which suffers the least refraction appears of red colour, the next adjoining part orange, then successively yellow, green, blue, indigo, and violet rays, the last being the most refracted. The images of these differently coloured rays produce the *spectrum*. Ordinary white light is therefore made up of several colours; the splitting up of white light into its elementary parts is called *dispersion.*

96. *Motion of light.* A beam of light travelling in the

direction *x y* (Fig. 157) causes every particle of ether to vibrate under right angles to this line. The maximum deviation from the line of equilibrium, *e.g.* the distance *a b*, is called the *amplitude* of the vibration. Any two particles of ether, such as *b* and *c*, placed in the same position relative to the line of equilibrium, are said to be *of like phase.* The distance *b c* is called the wave-length, and the time taken up in traversing this space is the *period of vibration.* The brightness of light is proportionate to the amplitude, while the colour depends on the wave-length. The time of vibration of the several coloured rays varies; the red rays, being the longest, vibrate at the slowest rate, after which come orange, yellow, etc. The violet rays, having the shortest wave-length, vibrate with the greatest velocity. If two waves similarly conditioned as regards direction, phase, and intensity meet they form a single wave of double amplitude. If they differ in phase they *interfere*, and produce a new wave (interference wave), the phase and amplitude of which accord with the parallelogram of forces. If the two waves are of opposite phase and the same amplitude they extinguish each other. Interference is always accompanied by dispersion, hence interference waves always exhibit the coloured rays of the spectrum.

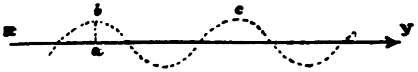


FIG. 157.

The particles of ether vibrate, of course, not in one plane only, as might be inferred from the diagram (Fig. 157), but equally all round the axis *x y*, and that part of the agitated surface the molecules of which are equally advanced is called the *wave-surface.* A medium in which light travels at the same rate in every direction, *i. e.* in which the wave assumes a spherical surface, is called *isotropic.* On the contrary, a medium in which light is propagated at an unequal rate in different directions, *i. e.* in which the wave-surface is ellipsoidal, or of a form other than a sphere, is said to be *anisotropic.*

97. *Double Refraction.* From the explanation given in par. 93 it is apparent that refraction is simply a deflection of an incident beam of light. In some substances, however, the refracted beam is divided into two rays, and they are accordingly said to possess the power of *double refraction.* Among the large section of doubly-refracting minerals the variety of calcite known as Iceland spar exhibits this property most prominently. Let, in Fig. 158, P represent a calcite rhombohedron, the section being laid through the principal axis and right-angled to two planes of the crystal. A beam *a b* perpendicular to these planes is divided into two: one, the *ordinary* ray, *b c*, which undergoes no refraction, and the other, the *extraordinary* ray, *b d*, which is refracted. Both rays on entering the rarer medium, *e.g.* air, pursue a direction *c f* and *d g* parallel to the original course. If a second prism A be now placed in parallel position beneath the first, the ordinary ray still continues its vertical course to *h*, while the extraordinary ray is again refracted to *g i.* Both rays after emergence resume their parallel courses *h o* and *i e.*

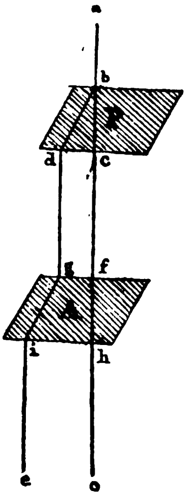


FIG. 158.

If the lower prism is turned horizontally (so as to leave the plane *f g* still parallel to the plane *c d*) to the extent of 90°, the extraordinary ray *d g* passes through the crystal without refraction, while the ordinary ray is refracted towards the observer, *i.e.* away from the plane of the section.

When the lower prism is turned horizontally to the extent of 180°, the ordinary ray passes through the medium unbroken as in the first case, while the extraordinary ray undergoes refraction in a direction towards the ordinary ray, the two rays merging into one at point *h* (Fig. 159).

In the intermediate positions of 45° and 135° four rays become visible (Fig. 160), refracted in two different planes right-angled to each other, as shown in plan, Fig. 161. Between the angles 135° and 180° the images *x* and *y* become gradually fainter and disappear at 180° (Fig. 159), while the images *o* and *z* coincide, and there remains but the one image *o*, which is four times as brilliant as that occupying the positions of 45° and 135°.

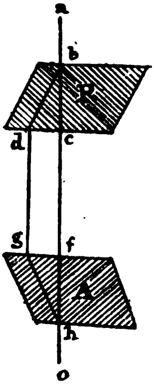


FIG. 159.

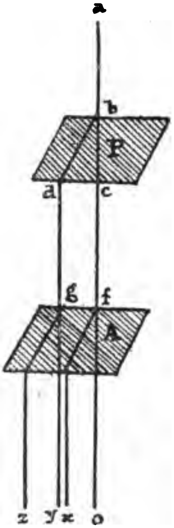


FIG. 160.

Calcite, in common with all other minerals crystallizing in the hexagonal system, possesses the power of double refraction in all directions except one, viz. that of the principal crystal axis. Light, therefore, passing through a calcite crystal in a direction parallel to the principal axis is singly refracted. Minerals crystallizing in the isometric system, as well as all amorphous minerals, that is to say which exhibit no trace of crystalline structure, are singly refracting or isotropic, *e.g.* rock-salt, obsidian. All other minerals are doubly refracting or anisotropic. Hence the important conclusion that a doubly-refracting mineral cannot belong to the isometric system, nor is its structure amorphous.

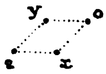


FIG. 161.

Minerals crystallizing in the tetragonal and rhombohedral systems are uniaxial, the optical axis being parallel to the principal crystal axis.

Minerals of rhombic, monoclinic, and triclinic crystallization are biaxial. In the rhombic system the optical axes are parallel to the diagonal crystal axes; in the monoclinic system one optical axis only is parallel to a crystal axis, viz. the orthodiagonal; while in triclinic crystals none of the optical axes are parallel to a crystal axis. Finally, minerals of isometric crystallization and amorphous minerals are triaxial.

98. *Polarization.* It has been stated that the wave-surface of light is that of a sphere or ellipsoid. Under certain conditions, however, vibration takes place in a single plane only, and the light so vibrating is found to have lost, either wholly or in part, the property of being further propagated or reflected. Light so conditioned is said to be *polarized.* Experimentally, polarization may be induced by four different methods, viz. by reflection, by a series of thin glass lamellæ, by two plates of tourmaline, and by Nicol prisms.

(1) *By reflection.* Let *b* and *c* in Fig. 162 be two parallel mirrors. A beam of light *a b* is reflected in the line *b c* and thence to *c d*. The ray *c d* is parallel to *a b* and is polarized. If the lower mirror *c* be now turned horizontally 90° the

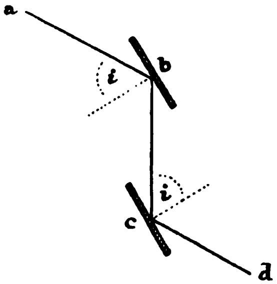


FIG. 162.

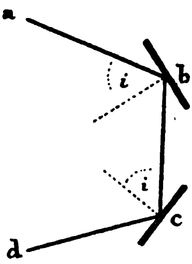


FIG. 163.

intensity of light is greatly diminished and may even be nil. On continuing the horizontal revolution the light will again increase, until at the angular distance of 180° (as shown in Fig. 163) it resumes its original brilliancy. It has been stated that the reflected ray in the crossed position of the mirrors may be nil; this is actually the case when the angle of incidence reaches a certain value. It is then called the *angle of polarization*, the tangent of which is equal to the index of refraction of the reflecting substance, *i. e.* tang. $i = n$. The incidental ray $a\,b$ in Fig. 162 manifestly vibrates in every direction. The reflected ray $b\,c$, however, is partially polarized, and vibrates only in a direction right-angled to the reflecting surface of the upper mirror. As the lower mirror is parallel to the upper one the ray $c\,d$ also vibrates in the same plane as $b\,c$, and is therefore reflected without other change. With crossed mirrors no vibration can take place in the direction normal to the lower mirror, hence the light is there extinguished. The plane of vibration normal to the plane of reflection is called the *plane of polarization*. In Fig. 156 the beam $a\,o$ is partly refracted and partly reflected; both rays are polarized; the refracted ray $o\,e$ contains only the vibrations that were lost in the reflected ray $o\,b$, that is to say, those vibrations which coincide with the plane of incidence and reflection. The separation of a beam of ordinary light into two rays, the one reflected, the other refracted, vibrating at right angles to each other, takes place most perfectly when these two rays are 90° apart. Here, as already stated, tang. $i = n$. For $n = \frac{\text{sine } i}{\text{sine } r} = \frac{o\,g}{o\,f}$ (Fig. 156), and if tang. $i = n$ then $a\,g = o\,f$, and $\wedge\, b\,o\,e = 90^\circ$; tang. $i = \frac{o\,g}{a\,g}$.

The angle of polarization of glass is about 54° 35′. Metallic reflectors polarize light to only a slight extent.

(2) *Polarization by tourmaline plates.* If two thin plates of tourmaline cut parallel to the optic axis of the crystal

(six, nine, or twelve-sided prism) are so placed that their axes are parallel, the brown and green colours of the mineral are clearly observable (Fig. 164). If now one plate is turned upon the other, light is gradually absorbed, and at the angular distance of 90° is completely extinguished, the mineral then appearing opaque (Fig. 165). For practical purposes the two plates are usually mounted in the frame of a pair of tongs made of elastic wire.

FIG. 164.

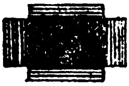


FIG. 165.

(3) *By glass plates.* A beam of light refracted is always partially polarized. Light falling upon a single glass slab will be but slightly polarized, but by transmission through other glass plates that have been placed in contact, polarization may be increased indefinitely by increasing the number of plates.

(4) *By Nicol prisms.* In practice it is found that the use of dark mirrors, tourmaline plates, or a set of glass discs is attended by considerable absorption of light, and polarization is but imperfectly effected. In both these respects the employment of calcite prisms has the advantage over other methods. Such prisms are named after the inventor "Nicol prisms," or simply "nicols." The cleavage angle of calcite is 71°. In preparing a nicol, the end planes of a calcite prism are ground down and polished so as to produce with the obtuse vertical edges angles of 68°, as shown in Fig. 166, where angle $b\ a\ e = c\ g\ f = 68°$. The prism is then cut through along the plane $b\ f$, and after being polished the two parts are re-united with Canada balsam. The face $b\ f$ makes with the basal planes angles of 89° 17′. All the faces are right-angled to the principal section of the crystal; this section, shown by shading in Fig. 166, extends from x to y in Fig. 167, which represents a plan of the Nicol prism. A beam of light $l\ m$, incident from below, is divided into two rays. The ordinary ray $m\ n$, vibrating in the plane of the

section, undergoes total reflection at the layer of balsam, and is ultimately absorbed by the blackened back of the prism

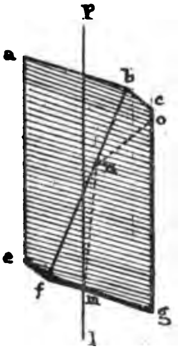


FIG. 166.

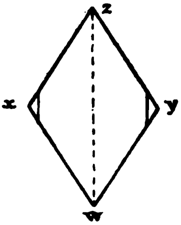


FIG. 167.

at *o*. The extraordinary ray passes through the prism and comes into view at *p*; it is polarized perpendicularly to the plane of the principal section, and its plane of polarization is called the polarizing plane of the nicol (*w z*). By placing a second prism above the first the ray *l p* will be extinguished if the plane of polarization is at right angles to that of the lower prism. In this position the nicols are said to be *crossed.* The lower nicol is called the *polarizer*, the upper nicol the *analyzer.*

99. *Microscopic examination.* Opaque minerals may be examined by *reflected* light through an ordinary magnifier. Transparent objects (if necessary a specimen is ground down to a thin transparent slice) are viewed by *transmitted* light by means of the microscope and reflector alone, or with the additional aid of polarized light. For the latter purpose it is requisite that the object be illuminated by polarized light, and that this polarized light enter the eye through another polarizing medium. The polarizer is placed between the source of light (the reflector) and the object, in line with the axis of the microscope. The analyzer is

placed either in the tube between the objective and ocular (Chevalier's method), or between the ocular and the eye (Talbot's method). The former method has the advantage that the field is noways contracted, and the disadvantage that the several parts of the tube have to be unscrewed and re-united whenever it is necessary to examine an object alternately in ordinary and polarized lights. In Talbot's arrangement the field becomes considerably contracted, but there is this advantage, that the analyzer can be readily removed and replaced, and the darkening of the field with crossed nicols is more perfect than is the case when the analyzer lies closely over the object glass, thereby causing an appreciable number of ordinary rays besides the extraordinary rays to reach the ocular lens. A beam of light passing the lower prism is polarized in a straight line: on entering the mineral it is doubly refracted and de-polarized: finally in the upper prism it is again reduced to rectilineal polarization. The result is that the doubly-refracting minerar is illuminated by more or less brilliant colours upon a dark ground when the nicols are crossed, and upon a luminous ground when they are parallel. These contrasts mark the mineral outlines with great sharpness, and enable the observer to perceive details by the polarizing microscope that are unrecognizable with ordinary light. If one of the nicols is turned the colour is changed; with crossed nicols the colour is complementary to that appearing with parallel nicols, *e.g.* red changes to green, blue to yellow, etc., and *vice versâ*. The nature and intensity of colour varies with the thickness of the mineral section, extremely thin slices fail to show any chromatic polarization.

100. *Diaphaneity.* A beam of light entering a substance may be wholly transmitted, partially transmitted, or wholly absorbed. In the first case the material is said to be *transparent*, *e.g.* glass, water, diamond, rock crystal. Even when the body is of considerable thickness an object may be seen through it with perfect distinctness. A substance

is *sub-transparent* when the outlines of an object are but indistinctly seen through it. When it transmits light freely but renders the outlines of an object invisible, a substance is called *translucent*, *e.g.* porcelain, felspar. When light passes only at the thin edges the substance is said to be *sub-translucent*, *e.g.* ivory, hornblende. Finally, when no light passes through a substance it is *opaque*, *e.g.* the metals. These several terms must be considered as merely relative, since even in the most pellucid minerals a certain amount of light is lost by absorption, while most minerals that are usually held to be opaque will, when cut into sufficiently thin slices, permit of the passage of light to an appreciable extent. The property of minerals to transmit light is termed *diaphaneity*.

101. *Colour.* The colours or shades of colour seen in minerals may be distinguished as metallic and non-metallic colours. The former are principally—silver white, bismuth white, tin white, copper red, bronze yellow, brass yellow, golden yellow, lead grey, steel grey, and iron black. The chief non-metallic colours are—white, reddish white, yellowish, greenish, bluish, and greyish white; crimson, cherry red, scarlet, brick red, aurora red; red brown, clove brown; sulphur yellow, lemon, orange, straw, and ochre yellow; smalt blue, azure, lavender, and indigo blue; emerald green, grass, leek, apple, olive, pistachio, and oil green; ash grey, pearl grey, bluish, yellowish, and blackish grey; velvet black, bluish, reddish, and brownish black.

If the colour is an essential property of the chemical compound that constitutes a mineral, as in the case of the metals and most metallic minerals, it will equally distinguish the mineral when in a solid mass and when in minute particles. Thus, whether in the massive or pulverulent condition, cuprite and hematite are of red colour, melaconite, pyrolusite, graphite are black, the salts of nickel green, etc. In most minerals, however, the colouring matter is some non-essential metallic oxide or carbon compound diffused through the mass, in which case a bulky sample may be of a relatively deep colour, while fine particles are of lighter shade or even white, *e. g.* fluorite, wavellite, tourmaline, and all coloured gem-stones. In yet other minerals colour is due to the adventitious presence of minute foreign bodies, or to secondary infiltration of a colouring solution into joints and capillary fissures of the mineral. Thus fine spangles of hematite sometimes give a blood-red colour to otherwise colourless minerals. The rust-brown colour frequently seen in mica generally arises from the deposition of thin films of ferric oxide on the cleavage planes. Mere traces of chromic oxide suffice to impart a bright green tint to quartz. In cases of this kind we have obviously to deal with mechanical impurities that are in no way characteristic of any particular mineral species.

102. *Streak.* Attention has been drawn in the last paragraph to the difference which frequently obtains in the colour of the mineral when in bulk and when in a state of fine subdivision. The former is properly called the *colour* of the mineral, while the colour of the powder is called the *streak.* Thus of the three native oxides of iron magnetite has a black colour as well as a black streak; hematite has a red-brown colour and cherry-red streak; limonite has a brown to black colour and an ochre-yellow streak. Most silicates have a streak lighter than their colour, while the reverse is the case with most minerals that have a metallic lustre. As a rule the streak affords greater aid in the determination of a mineral species than its colour.

To ascertain the streak of a mineral the most satisfactory way is to finely triturate a fragment of it in the agate mortar. In softer minerals the scratch of a knife generally produces sufficient powder to allow of its colour being recognized. A ready method is that of rubbing the mineral on the face of a piece of unglazed porcelain, and observing the colour imparted to it by the abraded material.

103. *Lustre.* Lustre results from the combined properties

of dispersion and reflection, and depends partly upon the refractive power of a mineral and partly on the capacity of its surface to reflect light. According to the degree of refractive force we distinguish *metallic* lustre, which is typical of the native metals and their sulphides; *submetallic* lustre, *e.g.* graphite, limonite; *adamantine*, *e.g.* diamond, anglesite; *vitreous*, *e.g.* quartz, azurite; *pearly*, *e.g.* talc, orpiment: *resinous*, *e.g.* opal, sulphur; *greasy*, *e.g.* some varieties of quartz, serpentine; *silky*, *e.g.* some varieties of gypsum, hornblende. According to the intensity of light reflected from the surface of a mineral the lustre is defined as *splendent* when the faces of the crystal or a newly-broken surface are capable of reflecting a perfect image, *e.g.* quartz, pyrite; *shining* when the image is only imperfectly defined, *e.g.* native copper, augite; *glistening* when light is reflected but no image is formed, *e.g.* some massive varieties of calcite and garnet. When there is no appreciable reflection of light, the mineral possesses no lustre and is said to be dull, *e.g.* meerschaum, wad.

104. *Pleochroism.* Light, both ordinary and polarized, passes through diaphanous isotropic minerals with equal velocity in every direction, and if the mineral is coloured the colour will appear of the same shade and depth in any layer of the same thickness in whichever direction it is viewed. Doubly-refracting minerals, however, transmit light differently in different directions, and when coloured and transparent, frequently exhibit two or more distinct colours when seen through in different directions. This property of refracting light of different colours is called *pleochroism*. Coloured optically-uniaxial minerals have usually two colours. Thus a crystal of zircon appears reddish-brown when looked at in the line of the principal axis, and green in that of the lateral axes. Tourmaline is opaque on the basal planes and brown on the prismatic section. Such minerals are said to be *dichroic*. Coloured optically-biaxial minerals frequently exhibit three, more or less distinct, colours according to the

direction in which light is transmitted. Thus iolite (rhombic) has the three colours, yellow, light blue, and dark blue; epidote (monoclinic) yellow, brown, and green; axinite (triclinic) green, violet, and brown. Minerals showing a different colour in three different directions are said to be *trichroic.*

105. *Iridescence.* Some minerals, when seen by obliquely-reflected light, exhibit on their surface more or less brilliantly-coloured bands or spots. This property, known as *iridescence,* indicates a want of homogeneity in the substance. Thus the blue and green bands on the cleavage planes of labradorite and the golden reflections in aventurine quartz and moonstone felspar are probably due to the presence of minute vesicles or crystalline particles of foreign minerals such as hematite, mica, hornblende, etc. Superficial iridescence is often induced by direct oxidation. Thus the oxides of iron and the sulphides of copper, antimony, and lead are particularly liable to tarnish on exposure, and acquire brilliant peacock colours.

106. *Opalescence.* The property possessed by some minerals, *e.g.* noble opal, cat's eye, and some varieties of felspar, to reflect and disperse light from numerous internal cracks and cavities, is called *opalescence.* Opalescent substances are usually of a bluish-white, translucent (milky) appearance, and the play of colours is in consequence as a rule subdued.

107. *Asterism.* Another feature due to interference of light is the appearance, both in transmitted and reflected light, of star-like reflections in some varieties of sapphire, biotite, labradorite, aragonite, etc. This phenomenon, known as *asterism,* has been ascribed in some cases to the presence of fine polysynthetic twin planes, and in others to the enclosure of symmetrically-arranged crystalline particles of a foreign mineral.

108. *Phosphorescence.* The property possessed by certain substances to emit light in dark situations, and known as

phosphorescence, is superinduced by direct exposure to sunlight, *e.g.* diamond, aragonite, barite, strontianite; by heat, *e.g.* fluorite, barite, apatite; by friction, *e.g.* sphalerite, quartz, dolomite, mica; or by electricity, *e.g.* corundum, fluorite, barite, diamond. Many artificial substances, *e.g.* loaf-sugar, the sulphides of calcium, strontium, and barium, etc., are eminently phosphorescent.

109. *Fluorescence.* In some substances the colour of the transmitted rays differs from that of the reflected rays. Thus light passing through certain kinds of naphtha appears colourless or pale yellow, while the reflected rays are blue to violet. Similarly some varieties of fluorite transmit a bright chrome-green light, while they reflect rays of a deep Prussian-blue colour. Such minerals are said to be *fluorescent.*

CHAPTER XIII

CHEMICAL PROPERTIES

110. *Composition.* Out of sixty-seven elementary substances known to the chemist, a considerable number occur under conditions with which the mineralogist is not concerned. The subjoined list contains the names, symbols, and atomic weights of those elements which are of mineralogical importance.

Aluminium	Al	27
* Antimony	Sb	120
* Arsenic	As	74·9
Beryllium	Be	9·1
Barium	Ba	137
* Bismuth	Bi	207·5
Boron	B	10·9
Bromine	Br	79·8
Cadmium	Cd	111·7
Calcium	Ca	39·9
* Carbon	C	12
Chlorine	Cl	35·4
Chromium	Cr	52·5
Cobalt	Co	58·7
* Copper	Cu	63·2
Fluorine	Fl	19·1
* Gold	Au	196·7
Hydrogen	H	1
Iodine	I	126·5
* Iridium	Ir	192·5

* Iron	Fe	55·9	* Selenium	Se	79
* Lead	Pb	206·4	Silicon	Si	28·4
Lithium	Li	7	* Silver	Ag	108
Magnesium	Mg	24	Sodium	Na	23
Manganese	Mn	54·8	Strontium	Sr	87·5
* Mercury	Hg	199·8	* Sulphur	S	32
Molybdenum	Mo	96	Tantalum	Ta	183
Nickel	Ni	59	* Tellurium	Te	125
Niobium	Nb	94	Thallium	Tl	204
Nitrogen	N	14	Thorium	Th	232
Osmium	Os	191	Tin	Sn	118
Oxygen	O	16	Titanium	Ti	48
* Palladium	Pd	106·7	Tungsten	W	184
Phosphorus	P	31	Uranium	U	239
* Platinum	Pt	195	Vanadium	V	51
Potassium	K	39	Yttrium	Y	89
Rhodium	Rh	103	Zinc	Zn	65
Rhuthenium	Ru	102	Zirconium	Zr	90·7

Only the sixteen elements distinguished by an asterisk in the above list have hitherto been found in a native state, *i. e.* as minerals. Although the number of distinct minerals comprises as many as 850 species and upwards of 2000 permanent varieties, the elements which enter into their constitution are relatively few, recurring as they do again and again in different combinations. The following, placed in the order of their greatest abundance, are the elements most frequently met with in nature—

Metalloids: O, Si, C, S, H, Cl, P, F, I, B.
Metals: Al, Ca, Mg, K, Na, Fe, Mn, As.

One or more of these elements takes part in the composition of all minerals, apart from the native metals.

111. *Chemical Formulæ.* The formulæ used to express the chemical composition of minerals are of two kinds, *empirical* and *rational* formulæ. The empirical formula gives simply the number of atoms of each element that enters into the constitution of the mineral. The rational formula attempts to group the atoms according to what is theoretically considered to be their combination in the mineral. The former convey facts ascertained from quantitative analysis; the latter, while of considerable assistance

to the understanding, assume conditions which are in most cases incapable of proof. Thus calcite has the empirical formula $CaCO_3$ and the rational formula $CaOCo_2$. Similarly the composition of orthoclase may be expressed by the empirical formula $KAlSi_3O_8$, or by the rational formula $K_2O.\ Al_2O_3.\ 6\ SiO_2$.

To convey the results of an analysis by a chemical formula the atomic ratio is obtained by dividing the amount of each constituent by its atomic weight. For example, the mineral crocoite is found to be composed of

$$\begin{array}{ll} \mathrm{Pb} & 63{\cdot}94 \\ \mathrm{Cr} & 16{\cdot}26 \\ \mathrm{O} & 19{\cdot}80 \\ \hline & 100{\cdot}00 \\ \hline \end{array}$$

$$\frac{63{\cdot}94}{206{\cdot}4} = 0{\cdot}31\ ;\ \frac{16{\cdot}26}{52{\cdot}6} = 0{\cdot}31\ ;\ \frac{19{\cdot}80}{{\cdot}16} = 1{\cdot}24$$

$$\mathrm{Pb} : \mathrm{Cr} : \mathrm{O} = 0{\cdot}31 : 0{\cdot}31 : 1{\cdot}24$$

or expressed in terms of the nearest whole numbers = 1 : 1 : 4.

The formula is therefore $PbCrO_4$.

On the other hand, the percentage composition may be computed from a given formula by reversing the operation just explained. Thus in the empirical formula for orthoclase, $KAlSi_3O_8$—

$$\begin{array}{lllcll} \mathrm{K} & = & 39{\cdot}1 & \dfrac{39{\cdot}1 \times 100}{278{\cdot}7} & = & 14{\cdot}03\ \mathrm{K} \\ \mathrm{Al} & = & 27{\cdot}3 & \dfrac{27{\cdot}3 \times 100}{278{\cdot}7} & = & 9{\cdot}80\ \mathrm{Al} \\ \mathrm{Si_3} & = & 84{\cdot}3 & \dfrac{84{\cdot}3 \times 100}{278{\cdot}7} & = & 30{\cdot}25\ \mathrm{Si} \\ \mathrm{O_8} & = & 128 & \dfrac{128 \times 100}{287{\cdot}7} & = & 45{\cdot}92\ \mathrm{O} \\ \cline{3-3}\cline{6-6} & & 278{\cdot}7 & & & 100{\cdot}00 \end{array}$$

In the rational formula for orthoclase $K_2O.\ Al_2O_3.\ 6\ SiO_2$—

$$\begin{array}{lcll}
K_2O = 78{\cdot}2 + 16 = 94{\cdot}2 & \dfrac{94{\cdot}2 \times 100}{557{\cdot}4} = & 16{\cdot}90 & K_2O \\
Al_2O_3 = 54{\cdot}6 + 48 = 102{\cdot}6 & \dfrac{102{\cdot}6 \times 100}{557{\cdot}4} = & 18{\cdot}41 & Al_2O_3 \\
Si_6O_{12} = 168{\cdot}6 + 192 = \underline{360{\cdot}6} & \dfrac{360{\cdot}6 \times 100}{557{\cdot}4} = & \underline{64{\cdot}69} & 6\,SiO_2 \\
\qquad\qquad\qquad\qquad\quad 557{\cdot}4. & & 100{\cdot}00 &
\end{array}$$

112. *Taste.* This property, distinguishable by the palate, is only possessed by such minerals as are soluble in water. The taste is *saline* in halite; *astringent* in copperas; *sweetish-astringent* in alum; bitter in epsomite; *cooling* in nitre; *alkaline* in trona.

113. *Odour.* Some minerals on being subjected to friction, heat, or moisture emit characteristic odours. A *fetid* odour is given off by some varieties of barite, calcite, and dolomite when rubbed or crushed. An *alliaceous* odour, resembling that of garlic, is emitted by native arsenic and sulphides of arsenic when heated. Compounds of selenium when heated have an odour of decaying horse-radish. Metallic sulphides yield a *sulphureous* odour under friction or heat. Some carbonaceous minerals have a *bituminous* odour even under normal conditions. Asphaltum and many other hydro-carbon compounds give off an *empyreumatic* odour when ignited.

114. *Touch.* The sensation felt by the finger or tongue on touching a mineral is of assistance in some cases. The *feel* or *touch,* as it is called, is described as *greasy, e.g.* in talc, graphite; *smooth,* as in kaolin, meerschaum; *harsh,* as in aluminite; *meagre,* as in magnesite. The avidity with which certain hydrous silicates absorb moisture can be easily recognized by touching the specimen with the moist finger or tongue. *Adhesion to the tongue* is a property not unimportant in the determination of haloysite, sepiolite,

aluminite, and other aluminous and magnesian hydrated silicates.

115. *Apparatus and reagents.* Examination for the determination of the chemical properties of minerals is conducted by two different methods. The one consists mainly in the application of heat, either *per se* or with the assistance of fluxes; this is called *treatment in the dry way.* The other conditions the use of a liquid menstruum, such as water or acids, in which the mineral is dissolved. The apparatus and reagents most essential in determinative mineralogy are those mentioned in the following list.

APPARATUS.

1. Steel hammer; face ½ inch square, back chisel-shaped, length 3 inches.
2. Anvil; cast-steel prism 1½ by 1½ by ¾ inches.
3. Steel mortar; ½ to ¾ inch diameter, with tight-fitting steel pestle.
4. Agate mortar; 2 to 2½ inches diameter, with agate pestle.
5. Pair of cutting pliers.
6. Pair of round wire pliers.
7. Three-cornered file.
8. Magnete, or magnetized knife-blade.
9. Floating magnet, or compass needle.
10. Magnifier.
11. Spirit lamp.
12. Oil lamp with flat wick, or gas-burner, or stearine candle with thick round wick.
13. Blowpipe.
14. Charcoal in blocks from 1 to 1½ inches square. The best wood for this purpose is that of the Brazilian araucaria. Australian pines also yield suitable material. The charcoal of Eucalyptus wood is not adapted for the purpose.
15. Platinum-pointed forceps.
16. Platinum wire, No. 27 gauge, cut in lengths of 3 inches.
17. Platinum spoon, ½ inch diameter.
18. Platinum foil.
19. Glass tubes, $\frac{3}{16}$ inch diameter, 4½ inches long, open at both ends.
20. Glass tubes of similar dimensions, closed at one end.
21. Glass test-tubes, ⅜ to ⅝ inch diameter, 2½ to 5 inches long.
22. Glass funnels, 1½ to 2 inches diameter.
23. Porcelain dishes, or casseroles, 1½ to 2 inches diameter.
24. Watch-glasses, unground, 1 to 2 inches diameter.
25. Wash-bottle.
26. Glass rods, 4 to 6 inches long.
27. Filter-papers, 2 to 3 inches diameter.

REAGENTS.

1. Soda bi-carbonate.
2. Borax.
3. Boric acid.
4. Microcosmic salt (salt of phosphorus).
5. Nitrate of cobalt solution.
6. Potassium bisulphate.
7. Potassium iodide.
8. Potassium oxalate.
9. Potassium antimonate.
10. Sulphur.
11. Metallic zinc.
12. Metallic magnesium, or sodium.
13. Metallic tin, granulated.
14. Tin chloride.
15. Fluorspar.
16. Gypsum.
17. Blue litmus paper.
18. Turmeric paper.
19. Brazil-wood paper.
20. Starch paper.
21. Distilled water.
22. Hydrochloric acid.
23. Nitric acid.
24. Sulphuric acid.
25. Potassa solution.
26. Ammonia.
27. Ammonium oxalate.
28. Ammonium chloride.
29. Ammonium molybdate.
30. Nitrate of silver.
31. Chloride of platinum.
32. Phosphate of soda.
33. Phosphoric acid.

116. *The Blowpipe Flame.* From the mineral to be examined a portion is selected which is free from any mechanical impurities likely to interfere with the reactions. The fragment, technically called the *assay*, to be of manageable size should not exceed one-eighth of an inch in any direction. When the assay is to be heated in a glass tube or on platinum foil the flame of a spirit lamp is ordinarily sufficient. In most cases, however, it is necessary to use the blowpipe flame, which both gives a higher temperature and is capable of effecting the oxidation and reduction of the assay. The *oxidizing flame* (Fig. 168) is produced by inserting the point of the blowpipe into the flame to about one-third of the breadth of the latter, immediately above the

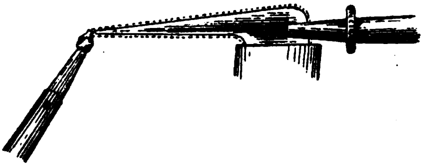


FIG. 168.

wick or gas-burner, and applying a rather strong blast. It will be noticed that the flame so produced is made up of an inner blue cone and an outer almost colourless mantle. The assay is held at the extremity of the outer flame where the oxidizing action is strongest. If the object is merely to test the fusibility of the mineral, the assay is brought in contact with the blue tip where the heat is most intense. The oxidizing flame should not exceed one inch and a half in length, and to this end the platinum nozzle of the blowpipe should have a rather narrow aperture.

The *reducing flame* (Fig. 169) is effected by bringing the point of the blowpipe just to the edge of the flame, at a height of about three-eighths of an inch above the wick and applying a somewhat feeble blast, only sufficient to bend the flame over from the vertical to an inclined position. It is an advantage to substitute a platinum nozzle with a somewhat larger aperture than that used for producing the oxidizing flame. The reducing flame should be luminous, yellow, and quite free from blue streaks. The reducing action is strongest near the apex of the flame. While it is necessary that the assay should be completely enveloped by the flame, it must not be inserted too far, lest it receive a coating of soot.

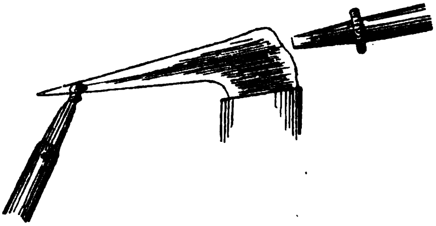


FIG. 169.

117. *Fusibility.* It is customary to express the relative degree of fusibility of a mineral by one of the figures 1 to 6,

which refer to certain type-minerals, known as the *Scale of Fusibility*, viz.—

1. Stibnite.
2. Natrolite.
3. Almandine.
4. Actinolite.
5. Orthoclase.
6. Bronzite.

Minerals having a fusibility of 1 melt in the ordinary spirit flame, *e.g.* sulphur, metallic lead. Those with a fusibility of 2 melt, even when in large fragments, to round beads in a feeble blowpipe flame, *e.g.* arsenopyrite, native silver. Minerals with a fusibility of 3 are fused to globules when in small fragments, *e.g.* fluorspar, metallic copper. Those with a fusibility of 4 do not yield globules, but thin fragments are completely rounded. Those of 5 yield to fusion only when in fine splinters; while those of 6 are merely rounded at the edges of extremely thin splinters. Minerals which after prolonged heating before the blowpipe exhibit no trace of fusion, *i.e.* which demand a melting temperature of more than 2200° F., are said to be *infusible.*

In testing the fusibility of a mineral the assay should be exposed to a pure oxidizing flame, as by the reducing action of the inner flame many oxides are converted to a condition in which they submit to fusion at a much lower temperature. Intumescence during heating must not be mistaken for fusion.

118. *Treatment in the closed tube.* A matrass made of glass tubing from one-eighth to a quarter-inch diameter, 4 to 5 inches long, and closed by fusion at one end, is thoroughly cleaned and dried. The assay having been inserted, the lower part of the tube is gradually heated in the spirit flame, and subsequently, if necessary, in the blowpipe jet. The heating being conducted with exclusion of the oxygen of the atmosphere, is essentially a reducing process. The following reactions are to be noticed.

(*a*) Decrepitation. The assay is shattered into small fragments either through simple expansion from heat, particularly in the case of minerals having a perfect prismatic cleavage (barite, fluorite, sphalerite), or through expulsion of moisture (many hydrates) or carbonic acid (many carbonates).

(*b*) Moisture condensed on the cool part of the tube. A thin film deposited on the first application even of a moderate heat indicates the presence of *hygroscopic moisture* (as in most pulverulent substances). At a higher temperature minerals lose their *water of crystallization*, which collects copiously in the middle part of the tube (*e.g.* zeolites). Finally, at a strong red heat the *water of composition* (basic water) is expelled, and will be found to condense slowly on the upper part of the tube (*e.g.* most hydroxides). By applying the heat cautiously and increasing it by degrees a means is afforded of determining in what condition or conditions water is present in a mineral.

If the water is of an acid nature, as in the case of compounds of sulphuric acid, fluorine, etc., that fact can be ascertained by inserting a strip of blue litmus-paper in the tube. On the other hand, the alkaline nature of the water, as in the treatment of nitrogenous hydro-carbons, or hydrates containing ammonia, is determined by means of a strip of turmeric paper.

(*c*) A coloured sublimate formed above the assay, viz.—

Sulphur—While hot, orange yellow; when cold, yellow. (Most metallic sulphides.)

Sulphide of arsenic—Hot, red brown to black; cold, yellowish red. (Realgar, arsenopyrite.)

Metallic arsenic—Hot and cold, black metallic ("arsenical mirror"). (Most arsenides.)

Mercury—Grey aggregate of small metallic globules. (All amalgams.)

Sulphide of mercury—Bluish black, with red streak. (Cinnabar, tetrahedrite.)

Sulphide with oxide of antimony—Hot, black; cold, cherry red to brownish red. (Stibnite.)

(*d*) Change of colour. All carbonates on parting with their carbonic acid change colour. Thus the blue and green carbonates of copper become black. White carbonate of lead turns orange red while hot, and yellow on cooling. The white carbonate of iron becomes black and magnetic. Colourless carbonate of lime becomes dull white. Many oxides change colour either temporarily (while hot) or permanently. Thus the red oxide of iron becomes black when heated, but resumes its normal colour on cooling. The white oxides of tin and bismuth become permanently yellow.

119. *Treatment in the open tube.* The tubing to be used is of hard glass, quarter-inch gauge, cut into lengths of 5 inches, and open at both ends. The heating of the assay takes place with free access of the atmospheric air, and is therefore mainly an oxidizing (roasting) process. The assay is inserted about an inch into the tube, the latter held in an inclined position, and the heating performed first in the spirit flame and afterwards, if necessary, in the blowpipe flame. To insure the complete roasting of sulphides, arsenides, and antimonides, the heat must be kept below the melting-point of the assay. A strip of moistened litmus-paper serves for the recognition of acid vapours. The following reactions are to be observed.

(*a*) *Odour.* Sulphides, arsenides, and selenides yield vapours with characteristic odours, viz. sulphurous acid with the odour of burning sulphur, arsenous acid with a garlic odour, and selenous acid with an odour resembling decaying horse-radish.

(*b*) *Fumes.* Antimonous acid (SbO_3) and tellurous acid are emitted as dense white fumes which condense in part as sublimates on the upper side of the tube.

(*c*) *Sublimates.* Most antimony compounds yield a yellowish-white sublimate of antimonic oxide (SbO_5), usually deposited on the under side of the tube. Native arsenic and all metallic arsenides produce a white crystalline deposit of arsenous acid. A metallic sublimate of mercury is formed by native mercury and most quicksilver compounds.

120. *Treatment on charcoal.* This is partly an oxidizing and partly a reducing process, by which the separation of the metals, and also some of the metalloids, into distinct groups may be readily effected. The following reactions are to be noted.

(*a*) The assay is volatilized with formation of sublimate at a moderate heat: sulphur, arsenic, antimony, tellurium, selenium.

(*b*) The same, but at a higher temperature: lead, bismuth, zinc, cadmium, tin.

(*c*) The assay fuses to a metallic globule: gold, silver, copper.

(*d*) The assay leaves an infusible mass: iron, nickel, cobalt, manganese, chromium, tungsten, platinum, osmium, iridium.

The assay is placed in a shallow cavity near the edge of the charcoal, and the latter inclined under an angle of about 45° to the blowpipe jet. For the production of the sublimates the oxidizing flame is as a rule employed; only in the treatment of the less volatile oxides of zinc and tin is the reducing flame necessary. The sublimates are deposited on the cool part of the charcoal at shorter or greater distances from the assay. The following are the most characteristic—

White to greyish white: Arsenic.

White to bluish white: Antimony.

Grey, sub-metallic: Selenium.

White nearest the assay, passing at a distance to reddish yellow: Tellurium.

Dark yellow while hot, pale yellow when cold, passing to bluish white: Lead.

Orange yellow while hot, paler on cooling, passing to bluish white: Bismuth.

Yellowish white passing to white, crystalline. The coating, rapidly heated, assumes a dark-blue colour, which after prolonged heating turns copper red: Molybdenum.

Pale reddish brown: Silver. In the presence of lead the coating is dark red; in the presence of antimony cherry red.

Yellowish white: Tin. Moistened with cobalt solution, re-heated, and allowed to cool, assumes a bluish-green colour.

Yellow when hot, white when cold: Zinc. Treated with cobalt solution becomes yellowish green.

In the examination of difficultly reducible oxides and silicates the assay is previously triturated and mixed with soda and a drop of water to a paste, which is then spread on charcoal and heated. (See par. 125.)

121. *Treatment with cobalt solution.* This operation is only of service when the assay is either white or yields a nearly white powder, and is moreover infusible or difficultly fusible. The substance is first strongly heated, then moistened with cobalt solution, and again ignited, without fusion, in a pure oxidizing flame. If the assay consists of a fragment it is held by the forceps; when it is in the state of powder it is moistened with water and taken up in a platinum wire loop. White sublimates on charcoal are treated directly on the support, as mentioned under tin and zinc in the last paragraph. The resulting changes are in each case to be observed when the assay has completely cooled. Under this treatment alumina assumes an azure-blue colour; magnesia a pink or flesh colour; oxide of zinc becomes yellowish green; oxide of tin bluish green. Silicate of soda, such as will result from fusing silica or a silicate with soda on platinum wire, yields with cobalt solution a smalt-blue bead. This reaction is therefore of service in the termination of the presence of silica, provided the assay is free from other colouring matter, boric acid or phosphoric acid.

122. *Fusion with borax.* The non-volatile metallic oxides dissolve in borax and form characteristically-coloured borates. To successfully apply this operation the assay

should contain neither metalloids nor volatile metals. Sulphides, arsenides, antimonides, compounds of lead, etc., should therefore be previously roasted on charcoal. A piece of thin platinum wire, three inches in length, is bent at one extremity into a loop about one-tenth of an inch in diameter. This is heated in the spirit flame and then rapidly brought in contact with the powdered borax, of which enough will adhere to completely fill the loop after fusion. A small portion of the powdered assay is now taken up with the hot bead and fused with it first in the oxidizing, and next in the reducing blast of the blowpipe. The complete reduction of the bead may be more speedily effected by adding a small grain of chloride of tin and fusing in the oxidizing flame. The colours should be observed while the glass is hot, and again when cold. Of the reactions to be noted the following are the most characteristic—

Metallic Oxides.	Oxidizing Flame.		Reducing Flame.	
	Hot.	Cold.	Hot.	Cold.
Iron.	Yellow to brown.	Pale yellow.	Bottle green.	Bottle green.
Chromium.	do.	Yellowish green.	Bluish green.	Yellowish green.
Tungsten.	Colourless to yellow.	Enamel white.	Pale yellow.	Yellowish brown.
Titanium.	do.	do.	Yellow to brown.	Brown, eventually enamel blue.
Vanadium.	do.	Greenish yellow.	Brownish.	Chrome green.
Uranium.	Yellow to red.	Colourless to yellow.	Dark green.	Dark green.
Molybdenum.	do.	Colourless to opaque grey.	Yellow to brown.	Brown.
Copper.	Green.	Blue.	Pale green.	Red, opaque.
Manganese.	Violet.	Amethystine.	Colourless.	Colourless.
Nickel.	Reddish violet.	Red brown.	Colourless.	Grey, turbid.
Cobalt.	Smalt blue.	Smalt blue.	Smalt blue.	Smalt blue.

The volatile metals and alkaline earths yield opaline, turbid, enamel-like, or quite opaque beads, mostly white or greyish of colour. Alumina dissolves to a colourless transparent glass.

123. *Fusion with microcosmic salt.* On fusion with ammonium-sodium phosphate the metallic oxides are converted into phosphates, the colours of which are with some

few exceptions similar to those observable in the borax glass. The several shades of colour are, however, generally purer and clearer, hence the treatment with microcosmic salt is to be preferred in cases where the quantity of colouring oxide in an assay is only minute. The circumstance that silica is practically insoluble in microcosmic salt is of service in the examination of silicates. In such cases the assay should be introduced in the form of a fragment (not in powder); the basic constituents of the silicate are readily dissolved, while a skeleton of opaque silica remains suspended in the transparent glass. The principal reactions are given in the following table—

Metallic Oxides.	Oxidizing Flame.		Reducing Flame.	
	Hot.	Cold.	Hot.	Cold.
Iron.	Yellow to brown (on cooling, green).	Pale yellow to brown.	Pale yellow to brown.	Bottle green.
Chromium.	Yellow to brown.	Yellowish green.	Yellow to brown.	Emerald green.
Tungsten.	Pale yellow.	Colourless.	Olive green.	Pale blue.
Titanium.	Pale yellow.	Colourless.	Yellow.	Violet.
Vanadium.	Yellow.	Pale yellow.	Brownish.	Chrome green.
Uranium.	Yellow.	Yellowish green.	Bottle green.	Bluish green.
Molybdenum.	Yellowish green.	Colourless.	Bottle green.	Green.
Copper.	Green.	Blue.	Colourless to green.	Red, opaque.
Manganese.	Brownish purple.	Reddish violet.	Colourless.	Colourless.
Nickel.	Red brown.	Yellow to orange.	Purple brown.	Grey, opaque.
Cobalt.	Dark blue.	Light smalt blue.	Dark blue.	Light smalt blue.

For the detection of fluorine the powdered assay is mixed with microcosmic salt which has been previously fused on charcoal. The mixture is placed in an open tube in such a position that it may be touched directly by the blowpipe flame, and the fumes driven out at the top of the tube. A strip of moistened Brazil-wood paper is inserted at the upper end of the tube. In the presence of fluorine the colour of the test-paper changes from red to straw yellow, and the inner side of the tube becomes corroded by the action of hydrofluoric acid upon the glass.

124. *Flame Coloration.* Most alkalies and alkaline

earths, the volatile metals, as well as phosphoric acid, boric acid, molybdic acid, etc., impart to the blowpipe flame characteristic colours. The delicacy of the reaction is in some cases enhanced by moistening the assay with hydrochloric or sulphuric acid. The blowpipe flame should be scarcely more than an inch in length and a perfectly blue oxidizing flame. By holding the assay just within the blue cone the outer flame beyond the assay is coloured. In some instances better results are obtained by bringing the assay in contact with the lower margin of the flame about half-an-inch to the right of the apex, when a more or less luminous coloured fringe will appear on the lower side of the flame. For the better observation of the colours it is advisable to place a dark screen behind the lamp, or spread a sheet of black paper on the work-table.

The test for flame coloration, like that for fusibility (par. 117), is best performed on a thin splinter, which is held in the platinum-tipped forceps in such a way that the blowpipe jet can be directed upon the extreme point of the projecting part of the assay. In the case of volatile or easily fusible substances the assay is placed in a cavity of a narrow stick of charcoal, about an eighth of an inch in width. Decrepitating minerals are powdered, moistened with distilled water, and taken up in a platinum-wire loop. Otherwise the paste may be spread on platinum foil and strongly heated, when it usually cakes together sufficiently firmly to be grasped in the forceps. Many substances composed wholly or partly of alkaline earths are rendered caustic by heat. The assay is in such cases strongly ignited, allowed to cool, and then placed on a slip of moistened turmeric paper. An alkaline reaction is indicated by the yellow colour of the test-paper changing to orange.

The chief flame reactions are given in the following list—

Soda	Yellow, luminous.
Strontia	Scarlet.

Chloride and bromide of copper		Azure blue, luminous.
Lime (particularly when moistened with hydrochloric acid)		Reddish yellow.
Lithia	do.	Carmine red.
Baryta	do.	Pale yellowish green, luminous.
Potash (particularly when moistened with sulphuric acid)		Violet.
Phosphoric acid	do.	Pale green.
Boric acid	do.	Bluish green, luminous.

Silicates containing boric acid are mixed with 1 part of fluorspar, 3 parts of bisulphate of potassium, and a drop of water. The paste is taken up on a platinum-wire loop, slowly dried, and then rapidly ignited in the blowpipe flame. On fusion the characteristic luminous green colour of boric acid will appear in the outer flame.

The volatile metals are best treated on a charcoal stick.

Arsenic colours the flame faint blue.
Lead ,, ,, ,, pale azure blue.
Zinc ,, ,, ,, whitish green, luminous.
Antimony ,, ,, ,, greenish blue.

125. *Fusion with carbonate of soda.* A few substances dissolve completely in molten carbonate of soda, and form with it fusible glasses, *e.g.* silica, the oxides of tungsten, molybdenum, titanium, etc. Another and more numerous class of substances unite with soda to difficultly fusible slags or infusible masses, *e.g.* most earthy compounds; while a third class of minerals, viz. those containing reducible metallic oxides, are decomposed, and the oxides brought to the metallic state.

The pulverized assay is mixed with soda and moistened with distilled water to a paste, which is spread on the support, gently dried before the blowpipe, and then heated in a strong blast. The support used is charcoal, excepting in the examination of manganese, when the platinum-wire loop renders the best service. The following are the most important reactions.

Sulphur, sulphides, and sulphates yield an *hepar*, that is to say, fuse with soda to a liver-brown or yellowish mass of sulphide of sodium, which on being placed on a clean surface of silver, and moistened with a drop of water, produces a black stain of sulphide of silver. Since coal gas is rarely free from sulphuretted hydrogen, the gas lamp must in this operation be replaced by an oil lamp or candle.

Silica fuses with effervescence to a water-clear bead of silicate of soda.

Oxide of titanium also fuses with effervescence, but the glass is yellow and crystalline on cooling.

Oxide of manganese treated with soda on platinum wire in the oxidizing flame forms a sea-green opaque mass of manganate of soda.

The reduction of the metallic oxides is performed by treating the assay in a cavity on charcoal for some time in a strong reducing flame. The spot operated upon is next moistened by a jet of water from the wash-bottle, and the part of the charcoal containing the reduced metal cut out with a knife to a depth of about half-an-inch, transferred to the agate mortar, and there finely triturated with water. The light particles of coal, slag, etc., are carefully removed by elutriation, while the reduced metal remains behind in more or less shining spangles that may be collected and, if necessary, identified by further treatment.

The oxides of chromium, manganese, titanium, uranium, platinum, and others of the rarer metals, cannot be reduced with soda on charcoal.

126. *Fusion with potassium bisulphate.* Potassium bisulphate is decomposed by heat to potassium sulphate and free sulphuric acid. When the fusion takes place in the presence of a compound containing a volatile acid or an haloid, the latter are attacked by the liberated sulphuric

acid. The assay is pulverized and mixed with the flux, and the heating conducted in a closed tube. Chlorides yield hydrochloric acid vapours; iodides violet fumes; bromides red-brown fumes of characteristic odour. These reactions do not, however, apply to the haloids of silver which are not decomposed by potassium bisulphate, but fuse to coloured beads, viz. chloride of silver, sulphur yellow when cold; bromide of silver, citron yellow when cold; iodide of silver, blackish brown while hot, garnet red on cooling, and orange to yellow when cold. When salts of chromium are examined a little chloride of sodium should be added to the flux; the fused mixture develops red-brown fumes which condense to perchloride of chromium.

In many cases confirmatory reactions are obtained through the use of test-papers, slips of which are placed at the open end of the tube. Thus Brazil-wood is of service in the detection of hydrofluoric acid; starch-paper in the presence of fumes of iodine and bromine; litmus-paper in the examination of chlorates; and filter-paper saturated with iron vitriol solution for the recognition of nitric and nitrous vapours.

The examination of carbonates is conducted by fusing the potassium bisulphate by itself in the matrass, and then adding the assay to the molten flux. By these means the evolution of carbonic acid can be readily observed.

127. *Fusion with potassium oxalate.* In some instances the reduction of metallic oxides on charcoal can be effected more completely with a feebler blast, and in less time with the aid of potassium oxalate than with that of carbonate of soda. In the treatment of difficultly reducible oxides such as the oxides of iron, cobalt, and tin, the substitution of this flux for soda is therefore a decided advantage. It is, however, in the detection of minute quantities of sulphur that this reagent is particularly serviceable. The powdered assay mixed with the flux is placed in a closed tube, gently heated over the spirit lamp till all moisture has been expelled, and

then strongly heated before the blowpipe. The substance, whether it contain sulphuric acid, sulphurous acid, or sulphur, yields an hepar (potassium sulphide), which on addition of a drop of water emits the odour of sulphuretted hydrogen. Or by breaking the point of the tube the dry contents may be removed on to moistened silver-foil in order to observe the instant production of a black patch of sulphide of silver. This treatment not only affords a more delicate reaction than the soda test on charcoal, but it removes the objection to the use of the gas flame, to which reference was made in par. 125.

128. *Fusion with magnesium.* When metallic magnesium (or sodium) is heated in contact with a compound containing phosphoric acid, but with exclusion of atmospheric air, it oxidizes at the expense of the oxygen of the phosphoric acid, while the resulting magnesium phosphide is on the addition of a little water decomposed with the evolution of phosphoretted hydrogen. The reaction afforded by this treatment is decisive in the case of pure phosphates, and helps in the recognition of even minute quantities of phosphoric acid. A piece of magnesium wire or foil, about an eighth of an inch in length, is inserted in the matrass so as to be completely enveloped by the finely pulverized assay. The blowpipe flame is directed to the lower part of the tube until a strong incandescence indicates that the reduction of the phosphoric acid has been accomplished. The tube having been allowed to cool, a slight moistening of the assay is shortly succeeded by the evolution of gaseous hydric phosphide, easily perceptible by its characteristic odour.

129. *Solubility.* The menstrua most frequently employed for testing the solubility of minerals are distilled water, hydrochloric acid, nitric acid, sulphuric acid, potassa solution, and ammonia. A mineral may be completely soluble, *e.g.* rock-salt in H_2O, calcite in HCl; partially soluble, *e.g.* biotite in SO_3; or insoluble, *e.g.* quartz. In partial solutions

one or several of the constituents of the mineral remain behind in a solid state. This residue may be either in a chemically unaltered condition, *e.g.* sulphur liberated when pyrite is digested in HNO_3, or it is a compound of one of the mineral constituents and the solvent, *e.g.* chloride of lead formed by treating jamesonite with HCl. Some minerals otherwise unaffected by acids become soluble or partially soluble after they have been ignited or fused, *e.g.* some varieties of garnet. Heat increases the solvent power of all fluids; in some cases complete solution is effected only on boiling the acid. Many silicates are decomposed by HCl, the silica separating either as a granular powder or in the form of a jelly. Under the last-mentioned conditions the mineral is said to "gelatinize with hydrochloric acid." Insoluble silicates may be rendered soluble in acids by previous fusion with carbonate of soda or other alkaline flux. Carbonates effervesce with acids through evolution of carbon dioxide. Sulphides frequently emit sulphuretted hydrogen when treated with HCl. Sulphates dissolved in HCl yield with barium chloride a white precipitate of barium sulphate. The nitric solutions of phosphates give on the addition of an excess of ammonium molybdate a yellow pulverulent precipitate. Chlorides dissolved in HNO_3 afford with nitrate of silver a curdy-white precipitate of chloride of silver. Nitrates are decomposed by strong SO_3 with evolution of nitric oxide. Fluorides similarly treated emit vapours of hydrofluoric acid which corrodes glass.

CHAPTER XIV

DISTRIBUTION AND CLASSIFICATION OF MINERALS

130. *Distribution.* In explaining the occurrence of a mineral in nature three distinct points have to be considered, viz. (1) local distribution, (2) geographical range,

and (3) geological habitat. The first applies to the absolute abundance or paucity of the mineral in a particular situation; the second refers to the occurrence of the mineral in different parts of the globe; the last alludes to diversity of age, character, and origin of the rocks in whose association the mineral is found. Limonite, *e.g.*, is found both widely dispersed over the globe and plentifully massed in defined spots, but its geological range is confined to the later formations. Magnetite, on the contrary, is found dispersed among rocks, both sedimentary and eruptive, of every age and in all parts of the world, yet there are comparatively few localities in which the mineral has attained any massive development. The distinction between absolute and relative distributions may be still better illustrated by a comparison between gold and cassiterite. The rarity of native gold stands in marked contrast to its extensive geological range (*vide* "Gold," *post*). Tin ore, again, is met with in veins and surface deposits of great bulk but strictly local extent, and while restricted to a few, geographically widely-separated, localities of the globe, its occurrence is attended by practically identical geological conditions.

It need scarcely be pointed out that the geographical distribution of minerals is liable to be materially influenced by local climatic, meteorological, and topographical conditions. Such soluble minerals as the haloids and salts, so abundantly produced in the arid regions of Atacama or Broken Hill, even at depths of five hundred feet below the surface, could not be formed, or if formed, could not be preserved in the humid mountain tracts of Nevada or Western Tasmania. Certain minerals which occur chiefly or solely in a fragmentary state, *e.g.* gem-stones, stream tin, placer gold, etc., owe their existence in detrital deposits to currents of water and a suitable fall of the land surface. In the absence of such surroundings the deposition of these minerals could not have taken place, however favourable the geological conditions for their production may have been in other respects.

While some minerals are to be met with under the most varied geological aspects in all parts of the globe, *e.g.* quartz, limonite, pyrite, calcite, etc., others have their occurrence restricted to a few places, *e.g.* diamond, asphaltum, meerschaum, platinum, mercury, etc. Not a few species, and a greater number of varieties, have only been observed in single localities, *e.g.* maldonite at Maldon, Vic.; seebachite at Richmond, Vic.; newberyite at Skipton, Vic.; marshite at Broken Hill, N.S.W.; awaruite on the Gorge River, N.Z.; cryolite in Greenland; sperrylite at Algoma, Canada, etc.

131. *Paragenesis.* The circumstance has long been recognized that certain minerals belonging to two or more distinct species have a tendency to occur in close proximity to one another, not infrequently with their crystals intergrown, and that this association remains practically constant under the most diverse geographical and geological conditions. It has hence been inferred that in such cases the particular minerals are of contemporary origin, and that the natural process which gave rise to one mineral may likewise have been favourable to, if not directly accountable for, the birth of the other. Minerals so disposed to associate are said to be *paragene*, *i.e.* "generated side by side." Common examples of paragenesis are the following—

Group of two members.	Three members.	Four or more members.
Gold, quartz.	Gold, quartz, arsenopyrite.	Gold, quartz, arsenopyrite, galena, sphalerite.
Cassiterite, quartz.	Cassiterite, quartz, tourmaline.	Cassiterite, quartz, tourmaline, wolfram, fluorite, topaz.
Galena, siderite.	Galena, siderite, dolomite.	Galena, siderite, dolomite, chalcopyrite, calcite.
Sphalerite, galena.	Sphalerite, galena, pyrrhotite.	Sphalerite, galena, pyrrhotite, garnet, quartz.
Bismuth, hornblende.	Bismuth, hornblende, magnetite.	Bismuth, hornblende, magnetite, fluorite, calcite.

132. *Nomenclature.* It is an unwritten law in modern

mineralogy that the names of minerals terminate in *-ite*, from the Greek *ites*, denoting a character or quality. In most instances the names are derived from Greek or Latin words signifying some property which is, or was at one time deemed, characteristic of the species; for example, orthoclase, from the Greek *orthos* and *clao*, normal-cleaving; cerargyrite from *keras* and *arguros*, horn-silver; albite from the Latin *albus*, white. In other cases the names bear reference to localities or persons; for example aragonite, from the Spanish province of Aragon; smithsonite, after the American naturalist Smithson. An exception to this general rule is made in the case of old-established names which run constantly through the pages of literature, or are words of every-day usage; *e.g.* diamond, topaz, and most other gemstones; gold, copper, and other native metals; quartz, hornblende, orthoclase, epidote, psilomelane, realgar, etc. The terminations *-ytes*, *-ine*, and *-ime*, formerly much in use, are now as a rule set aside for *-ite;* thus barite stands for the obsolete barytes; celestite for celestine; analcite for analcime. A few vernacular names have been, however, retained, *e.g.* serpentine, tourmaline, olivine. In some instances the old names are still used for groups of minerals, while the individual species have been re-named in accordance with the modern rule, *e.g.* felspar group, mica group, garnet group. Names ending in "spar" and "blende," which are merely miners' appellations, are no longer used by mineralogists.

133. *Classification.* In selecting a basis for the methodical arrangement of minerals into groups, species, and varieties, the first consideration should be how to insure a definite degree of consistency with scientific principles. Admitting that so far no system of mineral classification has been devised that meets fully the requirements of strict science, it is generally agreed that by no other arrangement can the natural affinities of mineral species be so prominently exhibited as by the *chemical system* of classification. Under

this system the species are placed in order according to the predominance of the relatively electro-positive elements which enter into their composition, that is to say, commencing with the eminently basic metals, K, Na, Mg, Zn, Fe, Al, Pb, Sn, Bi, Cu, Ag, Hg, Pl, Au, Sb, passing on to C and P, and finishing with the extreme negative elements O, S, N, Cl, Br, I, Fl. Such a scheme, rational and consistent though it appear from the chemical standpoint, leads unavoidably to the severance of existing relations with regard to the mode of occurrence, association, and economy of minerals, and since these relations are of primary interest to the miner, geologist, metallurgist, and engineer, it is felt to be a practical advantage to adopt the less rigidly scientific method of separating all minerals in the first place into two orders, viz. the non-metallic and the metallic minerals, grouping the species of each in correspondence with chemical relationship, and proceeding with the subdivision according to differences in morphological and physical characters. In the scheme adopted for the descriptive part of this work the base of a mineral constitutes the principal distinguishing factor, while the acid marks the subordinate division. Each metal with its oxides and salts is thus made to occupy a separate group. The general plan of classification will appear from the following outlines.

NON-METALLIC MINERALS.

CLASS I.—NATIVE ELEMENTS AND THEIR SIMPLE COMPOUNDS.

Carbon Group. 1. Diamond. 2. Graphite. 3. Natural Gas. 4. Petroleum. 5. Elaterite. 6. Asphaltum. 7. Anthracite. 8. Black Coal. 9. Brown Coal. 10. Succinite. 11. Retinite. 12. Tasmanite. 13. Ambrite.

Boron Group. 14. Sassolite. 15. Borax.

Sulphur Group. 16. Native Sulphur. 17. Selenium.

CLASS II.—HALOIDS AND SALTS.

Alkali Group. 18. Sal-ammoniac. 19. Nitre. 20. Trona. 21. Nitratite. 22. Halite. 23. Mirabilite. 24. Cryolite.

Alkaline Earths Group. 25. Witherite. 26. Barito-calcite. 27. Barite. 28. Strontianite. 29. Celestite. 30. Calcite. 31. Aragonite. 32. Dolomite. 33. Ankerite. 34. Apatite. 35. Anhydrite. 36. Gypsum. 37. Scheelite. 38. Fluorite. 39. Brucite. 40. Magnesite. 41. Epsomite. 42. Struvite.

Aluminium Group. 43. Kalinite. 44. Alunogen. 45. Alunite. 46. Wavellite. 47. Turquois. 48. Lazulite. 49. Monazite.

CLASS III.—SILICA AND SILICATES.

Silica Group. 50. Quartz. 51. Tridymite. 52. Opal.

ANHYDROUS SILICATES.

Amphibole Group. 53. Amphibole. 54. Crocidolite.

Pyroxene Group. 55. Augite. 56. Diopside. 57. Hypersthene. 58. Enstatite. 59. Wollastonite. 60. Spodumene. 61. Beryl. 62. Olivine.

Garnet Group. 63. Garnet. 64. Vesuvianite. 65. Epidote. 66. Zircon. 67. Axinite.

Mica Group. 68. Muscovite. 69. Lepidolite. 70. Biotite. 71. Lepidomelane.

Leucite Group. 72. Leucite. 73. Nephelite.

Felspar Group. 74. Orthoclase. 75. Sanidine. 76. Albite. 77. Oligoclase. 78. Andesine. 79. Labradorite. 80. Anorthite. 81. Amorphous Felspars.

Scapolite Group. 82. Wernerite. 83. Tourmaline. 84. Andalusite. 85. Topaz. 86. Staurolite. 87. Titanite.

HYDROUS SILICATES.

Pectolite Group. 88. Pectolite. 89. Laumontite. 90. Prehnite. 91. Apophyllite.

Zeolite Group. 92. Natrolite. 93. Scolecite. 94. Mesolite.

95. Analcite. 96. Chabazite. 97. Gmelinite. 98. Phillipsite. 99. Stilbite. 100. Heulandite.

Talc Group. 101. Talc. 102. Sepiolite. 103. Serpentine. 104. Bastite. 105. Saponite. 106. Smectite. 107. Glauconite.

Kaolin Group. 108. Kaolinite. 109. Pholerite. 110. Halloysite. 111. Pyrophyllite. 112. Pinite. 113. Cimolite. 114. Palagonite. 115. Selwynite. 116. Allophane.

Chlorite Group. 117. Chlorite. 118. Clinochlorite.

CLASS IV.—ALUMINA AND ALUMINATES.

119. Corundum. 120. Spinel. 121. Chrysoberyl. 122. Beauxite.

METALLIC MINERALS.

The following sequence has been observed in regard to each group: Native Metals, Sulphides, Tellurides, Arsenides, Antimonides, Sulpharsenites, Sulphantimonites, Sulphobismuthites.—Chlorides, Bromides, Iodides.—Oxides, Carbonates, Silicates, Titanates, Niobates, Tantalates.—Phosphates, Arsenates, Vanadates, Antimonates, Nitrates.—Sulphates, Chromates, Tellurates, Tungstates, Molybdates.

Gold Group. 123. Native Gold. 124. Sylvanite. 125. Nagyagite.

Silver Group. 126. Native Silver. 127. Argentite. 128. Stromeyerite. 129. Dyscrasite. 130. Freieslebenite. 131. Pyrargyrite. 132. Proustite. 133. Stephanite. 134. Polybasite. 135. Cerargyrite. 136. Embolite. 137. Bromyrite. 138. Iodyrite.

Copper Group. 139. Native Copper. 140. Chalcocite. 141. Covellite. 142. Chalcopyrite. 143. Bornite. 144. Tetrahedrite. 145. Bournonite. 146. Nantokite. 147. Atacamite. 148. Marshite. 149. Cuprite. 150. Melaconite. 151. Malachite. 152. Azurite. 153. Chrysocolla. 154. Chalcanthite. 155. Cuproscheelite.

Mercury Group. 156. Native Mercury. 157. Cinnabar, 158. Calomel. 159. Coccinite.

Lead Group. 160. Native Lead. 161. Galenite. 162. Jamesonite. 163. Boulangerite. 164. Boleite. 165. Massicot. 166. Minium. 167. Cerussite. 168. Pyromorphite. 169. Mimetite. 170. Vanadinite. 171. Anglesite. 172. Crocoite. 173. Stolzite. 174. Wulfenite.

Tin Group. 175. Native Tin. 176. Cassiterite. 177. Stannite.

Zinc Group. 178. Native Zinc. 179. Sphalerite. 180. Zincite. 181. Franklinite. 182. Smithsonite. 183. Hydrozincite. 183*a*. Aurichalcite. 184. Calamite.

Platinum Group. 185. Native Platinum. 186. Iridosmine. 187. Sperrylite.

Iron Group. 188. Native Iron. 189. Pyrite. 190. Marcasite. 191. Pyrrhotite. 192. Arsenopyrite. 193. Löllingite. 194. Magnetite.. 195. Hematite. 196. Goethite. 197. Limonite. 198. Menaccanite. 199. Iserite. 200. Chromite. 201. Siderite. 202. Tantalite. 203. Columbite. 204. Vivianite. 205. Scorodite. 206. Pharmacosiderite. 207. Melanterite. 208. Copiapite. 209. Wolframite.

Cobalt Group. 210. Smaltite. 211. Cobaltite. 212. Erythrite.

Nickel Group. 213. Pentlandite. 214. Niccolite. 215, Ullmannite. 216. Zaratite. 217. Garnierite. 218. Morenosite.

Arsenic Group. 219. Native Arsenic. 220. Realgar. 221. Orpiment. 222. Arsenolite.

Antimony Group. 223. Native Antimony. 224. Stibnite. 225. Cervantite.

Bismuth Group. 226. Native Bismuth. 227. Bismuthinite. 228. Tetradymite. 229. Bismite. 230. Bismutite.

Manganese Group. 231. Braunite. 232. Pyrolusite. 233. Manganite. 234. Psilomelane. 235. Wad. 236. Rhodochrosite. 237. Rhodonite.

Titanium Group. 238. Rutile. 239. Anatase. 240. Brookite.

Uranium Group. 241. Uraninite. 242. Liebigite.

Molybdenum Group. 243. Molybdenite. 244. Molybdite.

134. *Descriptive Order.* The order in which the characters of mineral species are described in the succeeding part of this work is as follows: (1) Crystallization, Structure, Cleavage. (2) Hardness, Specific Gravity, Lustre, Colour, Diaphaneity, Fracture. (3) Chemical Composition. (4) Blowpipe and other chemical characters. (5) Distribution, Mode of Occurrence, Secondary Forms, etc. (6) Observations bearing on the Economy of the Mineral.

135. *Abbreviations.* The following abbreviations have been used—

H.	stands	for	Hardness.
G.	„	„	Specific gravity.
Comp.	„	„	Chemical composition.
Pyr.	„	„	Pyrognostic and other chemical tests.
BB.	„	„	Before the blowpipe.
F.	„	„	Fusibility.
OF.	„	„	Oxidizing flame.
RF.	„	„	Reducing flame.
Loc.	„	„	Localities.
Q.	„	„	Queensland.
N.S.W.	„	„	New South Wales.
Vic.	„	„	Victoria.
S.A.	„	„	South Australia.
Tas.	„	„	Tasmania.
W.A.	„	„	Western Australia.
N.Z.	„	„	New Zealand.
Var.	„	„	Varieties.
Econ.	„	„	Economy of mineral.

PART II

DESCRIPTIVE MINERALOGY

NON-METALLIC MINERALS

CARBON GROUP

ALL carbonaceous minerals are combustible, and BB either disappear altogether or leave a residue of ash. Fused with nitre they deflagrate and form K_2CO_3, which effervesces with acids.

1. DIAMOND. Isometric; tetrahedral, octahedral, triakis- and hexakisoctahedral, rarely in cubes. The faces as a rule curved and sometimes striated. Crystals often distorted. Twinning on the plane of the octahedron rather common. Also occurs in globular masses with roughened surface, the roughness being due to crystalline intergrowth. Also in rounded grains, rarely massive. Cleavage octahedral, very perfect.

H 10, generally less on the octahedral than on the cubical faces. G 3·15 in black varieties, 3·52 in crystals. Lustre adamantine to resinous. Colour water-clear, pale yellow, black, rarely green and blue. Transparent to translucent and opaque.

Var. The black diamond called *carbonado*, and the grey called *boort* or *bort*, possess a crystalline structure and indistinct cleavage, and are harder but less dense than the crystals.

Comp. Pure carbon when colourless and crystallized.

Pyr. BB in a strong heat is entirely converted into CO_2. Some of the darker kinds yield from 1 to 2 per cent. of ash.

Loc. Beechworth district, Vic., in recent valley gravels resting on granitic rocks. Echunga, S.A., in auriferous drift overlying palæozoic slate and sandstone. New England, N.S.W., in stanniferous gravel drift, the country rock being granite and felsite porphyry. Bingera and Mudgee, N.S.W., in pliocene conglomerate consisting of pebbles and boulders of quartz, quartzite, Lydian stone, jasper, slate, and sandstone cemented by iron and manganese oxides and silica. The conglomerate rests on palæozoic slate and sandstone, and is in places capped by basalt. Similarly at Mary River, Q. Brazil, in alluvial gravels apparently derived from the degradation of mica schist and itacolumite. Similarly in Georgia and North Carolina, U.S.A., and in the Ural. Madras, Panna, and elsewhere in India, in detritus resting on metamorphic slates and sandstones, traversed by eruptive rocks. California, in auriferous gravels. Borneo, in valley gravels carrying platinum. In the several localities mentioned diamond is usually associated with topaz, sapphire, corundum, zircon, pleonaste, schorl, rutile, brookite, magnetite, menaccanite, also gold, osmiridium, cassiterite, etc. In no instance has diamond been observed in its matrix, and the original source of the mineral remains so far unknown. Kimberley, South Africa, embedded in peridotite which has filled cylindrical vertical pipes from 100 to 320 yards in diameter, apparently of volcanic origin. The peridotite is a compound of diallage, diopside, olivine, enstatite, chromite, pyrite, garnet, biotite, and secondary calcite and zeolites. At the principal mine the volcanic pipe has been followed downward for a depth of over 1000 feet. The wall rock consists of 3 feet surface soil, 90 feet decomposed basalt, 200 feet carbonaceous pyritous shale, 10 feet quartz conglomerate, 400 feet porphyritic and amygdaloidal olivine diabase, 355 feet quartzite, 20 feet shale (not pierced). For some distance from the surface the peridotite is quite decomposed (yellow ground), but it passes gradually into a hard bluish-green rock (blue ground). Not unfrequently the crystals of diamond are broken and disjointed, a circumstance which has led some observers to infer that the mineral has had a deep-seated origin, the fragmentary condition of the crystals being attributed to mechanical force produced by volcanic action. By others it is held that the diamond has been generated *in situ* by the action of heat on the carbon shales which form part of the country rock.

Econ. The share which South Africa takes in the world's production of diamonds amounts at present to not less than 95 per cent. The outcome of the De Beers mines, Kimberley, during the five years 1890-94 is officially stated to have been close upon eleven million carats (over two tons), of the declared value of £15,500,000, or an average of twenty-eight shillings per carat. In the year 1893 a single stone weighing 970 carats was obtained, the largest ever discovered in South Africa. Some two years later a carbonado was found in Brazil which weighed 3100 carats, and is the largest diamond found in any part of the world. The only places in Australia where diamond mining is systematically carried on at present are Bingera and Mudgee, N.S.W. The largest single stone obtained in New South Wales weighed 7⅛ carats. Of the few hundred diamonds that have been found in Victoria in the course of thirty-five years none has exceeded a weight of 2½ carats. On account of its imperfect cleavage the Australian diamond offers in the cutting and polishing a practically uniform resistance in every direction. Moreover, the faces and edges of the natural crystals are as a rule rendered so indistinct as to afford the lapidary little or no guidance in discriminating between the softer faces and the harder "corners." The stone is in consequence looked upon by the trade as abnormally "hard," and in spite of the fact that no less than 25 per cent. of the diamonds raised in Australia have proved to be of "first water," *i.e.* of perfect brilliancy and free from flaws, the difficulty of cutting them has necessarily operated against their chances in the competition with African diamonds.

2. Graphite (syn. Plumbago, Black Lead). Rhombohedral, in hexagonal plates. Foliated, or disseminated in scales and grains. Cleavage perfect, basal. Laminæ flexible but inelastic. Touch unctuous.

H 1 to 2. G 2·1 to 2·3. Lustre metallic to sub-metallic, sometimes dull. Colour iron black to lead grey. Opaque. Conducts electricity, while diamond, which is chemically the same substance, is a non-conductor.

Comp. Pure carbon, generally with some oxide of iron and clayey matter. An increase in the quantity of these impurities is liable to affect the hardness and specific gravity of the mineral.

Pyr. Like diamond, but usually leaves a considerable residue of ash.

Loc. The auriferous quartz veins in many parts of Victoria and elsewhere are frequently contained within selvages of foliated graphitic clay. A sample from Ballarat has the following composition—

Carbon	15·8
Iron oxide	10·8
Clayey matter	73·4
	100·0

New Zealand: Nelson; Waiokura Creek, Waimate; Malvern Hills; Dunstan; Pakawau; Wellington.—Queensland: Gympie; Mt. Bopple in the Burnett district; Cape Upstart.—New South Wales: Tenterfield and Dundee in granite; Sydney in small grains in the Hawkesbury sandstone.—South Australia: Port Lincoln, Woodside.—Borrowdale, Cumberland in Cambrian slates; Cummock in Ayrshire, forming a seam three to six feet thick, partly composed of anthracite. —Ceylon; Siberia; Canada; Lake George, U.S.A.

Graphite is probably always the result of complete metamorphism of organic matter. It forms independent layers in strata of archæan and palæozoic age. Coal-seams are sometimes altered to graphite by contact with intrusive rocks. Also occurs in nests and disseminated grains in granite, greenstone, metamorphic schists, sandstone, limestone, etc.

Econ. The greater part of the world's supply of plumbago consists of graphite, which is intermixed to an indefinite extent with quartz, clay, iron oxide, and other impurities. Material of this class is ground, elutriated, and compressed, and when so treated is extensively employed in the manufacture of crucibles, lubricants, etc. The purer kind of plumbago, which in its raw state is suitable for lead pencils, is obtained chiefly at Ceylon, Ticonderoga in the State of New York, Buckingham and Grenville in Canada, and Siberia.

3. NATURAL GAS. The several hydrocarbon compounds usually included under the generic name of *bitumen* have the general formula CnH_{2n+2}. Three of these, viz. CH_4, C_2H_6, and C_3H_8, are at ordinary temperature gaseous. Those whose composition lies between C_3H_8 and $C_{16}H_{34}$ are liquids (petroleum, naphtha, etc.), while those above $C_{16}H_{34}$ are either viscous (elaterite, etc.) or solids (asphaltum, etc.).

Natural Gas is a simple hydrocarbon, having the general composition CH_4, which is also that of marsh gas. There is always present, however, a considerable proportion, amounting sometimes to 25 per cent., of hydrogen, ethylhydrite, carbonic acid, and carbon monoxide. Its specific gravity, compared with atmospheric air, ranges from 0·7 to 0·9.

Loc. Occurs under conditions similar to those referred to under petroleum (which see) in Western Virginia, Ohio, and Indiana, U.S.A., where borings, 800 to 1000 feet in depth, descend into the Trenton limestone (Lower Silurian). The great volumes of gas discharged by these bores are laid under contribution for technical and industrial purposes.

Fire Damp is a mixture of light carburetted hydrogen (CH_4) and heavy carburetted hydrogen (CH_2), the former predominating. It is mostly produced in coal-pits, particularly in newly-broken faces.

4. PETROLEUM (*Naphtha*, *Mineral Oil*). Liquid; colourless, yellow to dark brown. Naphtha is the limpid, thinly-fluid variety; rock-oil is yellow or brown, and of oily consistency; rock-tar is dark brown to black and viscous. G 0·6 to 0·9.

Comp. C_8H_{10} to $C_{18}H_{20}$, usually with some oxygen and nitrogen.

Pyr. In closed tube mostly volatilizes to inflammable vapour, leaving a tar-like residue.

Loc. Petroleum has been occasionally met with in connection with eruptive rocks, as at Taranaki, N.Z., where it issues from fissures in trachytic tuff, and on the island of Ramri in Burma, where it is discharged from mud volcanoes. Generally, however, it is found in sands, sandstone, clay, and marl, and hence have arisen the terms "oil shale," "pyroschist," "bituminous marl," etc. It occurs in New Zealand in the tertiary tract between East Cape and Hawke Bay in a free liquid state. At Mongonui, Durville Island, and Chatham Island impregnating shale (pyroschist). At Leigh's Creek, S.A., the mesozoic carbon shales contain, besides a small proportion of free petroleum, some 10 per cent. of fixed carbon, and 14 per cent. of volatile hydrocarbons. In the States of Pennsylvania and New York, U.S.A., in carboniferous and Devonian strata, passing further north, in Canada, into Silurian sediments. Borings have proved the productive oil-measures of this region to depths varying from 70 to 2800 feet. Nevada—in cretaceous strata. California—in pliocene sediments. Caspian region in Russia—in miocene sands and marls. Baluchistan in India—in cretaceous beds. Assam, Pegu, Burma—in nummulitic strata.

Petroleum is apt to find its way from the oil-producing layers to cavities in the adjacent barren rock, and there forms natural, subterranean reservoirs. The oil is protected by the overlying impervious rock against evaporation, oxidation, and dispersion, and moreover is frequently subjected to artesian pressure. It is sometimes found floating on stagnant water at the surface, where it has been carried by ascending springs.

The source of petroleum is usually ascribed to the decomposition of vegetable and animal matter (sea-weed, molluscs, mammalian and fish remains) that were distributed through arenaceous, calcareous, or clayey sediments, principally of marine origin. The conversion of an organic substance into bitumen conditions the exclusion of oxygen (air or water), and probably also the presence of such alkaline salts as the chlorides of sodium, magnesium, and potassium, sulphate of magnesium, etc., which are common constituents of sea-water. The frequent association of petroleum and gypsum has given rise to the suggestion that the carbon and hydrogen required in the formation of this and other bituminous bodies may have been derived from inorganic sources. Limestone, it is argued, contains about 12 per cent. of carbon, and when acted upon by volcanic gases, sulphuretted hydrogen, and steam, is transformed into hydrous sulphate of lime, while the liberated carbon unites with hydrogen in the production of paraffin or natural gas. The reaction may be shown thus—

$CaCO_3 + 2\ H_2S + H_2O = CaSO_4H_2O$ (gypsum) + C_2H_4 (paraffin).

$CaCO_3 + 3\ H_2S + H_2O = CaSO_4H_2O$ (gypsum) + CH_4 (carburetted hydrogen).

A cube mile of limestone (equal to a tract ten miles long and one mile wide, with a thickness of 528 feet) contains

1300 million tons of carbon, capable of aiding in the production of 1500 million tons of petroleum.

5. ELATERITE (Elastic Bitumen). Amorphous, resembling leather or india-rubber.

H less than 1. G 0·9 to 1·2.

Comp. C 85, H 13, O 2 = 100.

Pyr. In the open flame burns with an empyreumatic odour. Mostly soluble in ether, partially soluble in alcohol.

Loc. Derbyshire, Scotland, and elsewhere in carboniferous limestone.

Var. *Coorongite*, composed of C 66, H 12, O 20, Ash 2 = 100, is found in superficial deposits at Lake Coorong, S.A.

6. ASPHALTUM (Mineral Pitch). Amorphous, massive, conchoidal.

H 0·5 to 1·5. G 1 to 2. Lustre resinous. Colour brown to black. Odour pitch-like.

Comp. Oxygenated hydrocarbon of very variable composition. A sample from Kangaroo Island, S.A., afforded C 75·50, H 9·31, O 10·42, N 2·11, Ash 2·66 = 100.

Pyr. F 1; burns with a yellow flame and bituminous odour. In closed tube yields oil and tar. Partially soluble in boiling ether, yielding a solution with a red-brown colour.

Loc. Along the coast of South Australia, Port Lincoln, Kangaroo Island, Encounter Bay, and thence eastward as far as Portland, Victoria, in detached lumps apparently transported from a foreign source, and left by receding waves.—Trinidad, occupying a lake-like depression a mile in diameter. The asphaltum in the central part of the lake is in a molten condition. The sub-lying strata contain coal-seams.—Val de Travers, Switzerland, in cretaceous limestone.—Seyssel, in France, in chalk and greenstone.—Hanover, in Permian sandstone.

Asphaltum and elaterite are probably produced by the oxidation of mineral oils that have been inspissated by evaporation.

Mineral Coal consists essentially of carbon and bitumen in indefinite proportions, and includes a number of varieties, each of which is itself a mixture of two or more oxygenated hydrocarbons. The practice of including heterogeneous material of this kind among minerals is, it must be admitted, a questionable one, and is only justifiable from considerations of expediency. The fossil fuels may be conveniently separated into three species, viz.: 1. Non-bituminous Coal (Anthracite), 2. Bituminous anhydrous Coal (Black Coal), 3. Bituminous hydrous Coal (Brown Coal). That mineral coal is derived from vegetable substance is in many cases proved by its microscopic structure, and judging from analogy, as well as in view of the geological conditions under which they occur, it is now generally believed that all mineral coals, whatever their structure, are of phytogenic origin. The following table, which gives roughly the composition of the allied carbon compounds, serves to indicate the several stages in the process of alteration of the living fibre to non-bituminous coal. (The percentage of moisture, sulphur, and ash has in all cases been omitted.)

	C.	H.	O.	N.
Plant fibre	52	5	42	1
Peat	59	5·2	35	0·8
Lignite	62	5·4	32	0·6
Brown coal	69	6·5	24	0·5
Cannel coal. . . .	84	6·6	8	1·4
Cherry coal. . . .	86	5·3	9	3
Splint coal	87	3·8	9	0·2
Anthracite	96	3	0	0

That the character of the coal has been to a greater or minor extent influenced by the nature of the plant—whether fuci, lycopods, ferns, or conifers, etc.—from which it has been derived seems highly probable. Other conditions being equal, the gradual elimination of bitumen and the ultimate conversion of vegetable matter into anthracite is simply a question of time. Peat is a modern (recent or post-tertiary) product; lignite and brown coal are mostly of tertiary formation; black coal is of mesozoic and upper and middle palæozoic age; while anthracite, which is a secondary product, derived from the de-bituminization of black coal, and even of lignite, is met with in coal-bearing strata of every age, usually associated with younger eruptive rocks.

7. ANTHRACITE (*Glance Coal*). Compact, with conchoidal fracture.

H 2. G 1·3 to 1·8. Lustre vitreous to sub-metallic, often iridescent. Colour iron black to velvet black. Opaque.

Comp. Fixed carbon 89—94, Volatile hydrocarbon 1·4—6, Ash 1—5. With increasing amount of bitumen passes into *anthracitic coal*, which contains from 8 to 12 per cent. of volatile matter.

Pyr. Infusible; burns with weak flame and little smoke. Imparts no colour to boiling potassa solution or ether.

Loc. Extensively developed in Pennsylvania, U.S.A., and South Wales, where it is observed that the anthracite in the lower part of the coal basin generally passes into bituminous coal towards the margin of the basin. The impure variety "anthracitic coal" is more commonly met with, but the deposits are rarely of any great extent.—Mittagong, N.S.W. (permo-carboniferous); Malvern Hills, N.Z. (cretaceous); Newtown, near Hobart, Tas. (jurassic), always in connection with intrusive rocks. Carbonaceous shales and slates of Silurian and Cambrian age frequently owe their black colour to the presence of minute particles of anthracite.

Culm (Stone Coal) is a slaty variety resembling indurated carbonaceous shale, and containing much ash.

Carbonite (Native Coke) is a finely-porous, sintery, non-bituminous coal, dull black with interspersed shining parts, as if imperfectly fused. It is a product of contact metamorphism: thus at Lucia Bay, South Africa, where a forty-foot seam of glance coal is invaded by a basalt dyke.

8. BLACK COAL (*Bituminous Coal*). Massive; splits up

more or less readily along the laminations, *i. e.* parallel to the bedding planes of the seam, and is usually jointed in two other directions approximately normal to the bedding planes, whence it has a tendency to break up into rudely-prismatic fragments. The more prominent of these two sets of joints is called by colliers the *cleat*. The direction of the cleat is often persistent over a large extent of the field, and is taken advantage of in laying out the stalls of the colliery. Fracture uneven to sub-conchoidal; brittle.

H 0·5 to 2. G 1 to 1·8. Lustre differs in different varieties from dull and earthy to resinous, vitreous, and sub-metallic. Colour black to brownish black.

Comp. Fixed carbon 45—75, Volatile hydrocarbons 14—45, Ash 2—14. Usually contains sulphur, sometimes to the extent of 3 per cent., and moisture up to 6 per cent.

Pyr. Fusible to infusible. Burns freely and with much smoke. In closed tube yields oil and tar. Insoluble in boiling potassa solution, or at most imparts to it but a faint brown colour.

Loc. Forms subordinate layers, or *seams*, in strata of various ages. The most productive coal-measures occur in rocks ranging from Upper Carboniferous to Trias, *e. g.* New South Wales, Queensland, Tasmania, Western Australia; but deposits of great economic importance are known to ascend into Upper Jurassic (Gippsland, Vic., Ipswich, Q., Newtown, Tas.) and cretaceous strata (Winton, Q., New Zealand).

Var. (*a*) *Cherry Coal;* soft, often made up of thin layers of different lustre. Non-caking, burns freely without fusion, and is rapidly consumed.

(*b*) *Splint Coal;* dense and hard. Contains less volatile matter, and burns less freely than cherry coal.

(*c*) *Caking Coal;* brittle. Fuses readily into clinkers (coke), a property which is diminished or altogether lost by lengthy exposure to the air.

(*d*) *Cannel Coal;* compact, devoid of lamination; dull, brown, grey to black; conchoidal fracture. Highly bituminous, whence eminently suitable for the manufacture of gas and oil. *Kerosene shale* is a brownish-black, sub-resinous cannel coal from Hartley, N.S.W., with the composition—Fixed carbon 6, Volatile 82, Ash 12. With an increasing amount of fixed carbon and an increase of ash the cannel coals pass into oil shales (see Petroleum).

(*e*) *Mineral Charcoal* (Mother of Coal); very soft, fibrous, silky. Occurs in thin layers, and quite subordinately, with other coals.

9. Brown Coal (Hydrous bituminous Coal). Massive, dense or laminar.

H 0·5 to 1·5, softer than black coal. G 1 to 1·2, rarely 1·3. Various shades of brown, brownish black to black. Lustre bright to earthy, sometimes resinous.

Comp. Hygroscopic moisture 7—48, Volatile hydrocarbons 20—50, Fixed carbon 10—38, Ash 0·5—40. Sulphur rarely absent, sometimes amounting to 3 per cent.

Pyr. In closed tube yields much water, and the hydrocarbon is distilled over in the form of oil and tar. Partly dissolved in potassa solution, colouring the latter dark brown.

Loc. Brown coal occurs in basin-shaped, lacustrine deposits, usually of tertiary age, in many parts of the globe. For Australasian localities see table of analyses on opposite page.

The better class of brown coal, so-called *pitch coal*, resembles black coal in colour, lustre, and structure; the inferior kinds are light brown, soft, and earthy. The term *lignite* should be restricted to those brown coals which possess an eminently woody texture. *Jet* is a brittle, lustrous, black variety, only found in thin seams of subordinate extent.

10. Succinite (*Amber*). Massive, with conchoidal fracture.

H 2 to 2·5. G 1·09. Lustre resinous. Colour various shades of yellow, whitish, golden yellow, and yellowish brown; sometimes mottled and cloudy. Transparent to translucent. Frictio-electric.

ANALYSES OF BROWN COAL.

	Water.	Volatile.	Carbon.	Ash.	Sulphur.
Horsham, Vic.	6·88	46·93	40·75	4·41	1·03
Tasmania	18·81	48·74	29·26	3·19	—
Lal Lal, Vic.	28·30	31·44	35·29	2·89	2·08
Lal Lal, Vic. (Lignite) . .	40·77	22·80	35·70	0·67	0·06
Bacchus Marsh, Vic. . . .	37·33	21·09	29·50	10·25	1·83
Gippsland, Vic.	17·63	40·85	37·24	3·81	0·47
Gippsland (Lignite) . . .	25·90	26·83	37·29	8·30	1·68
Skipton, Vic.	29·88	27·13	19·70	23·29	—
Skipton (Lignite)	26·09	22·10	11·48	40·33	—
Leigh's Creek, S.A. . . .	18·80	24·95	52·90	3·35	—
Kuntha Hill, S.A. . . .	16·40	28·44	45·77	8·36	1·03
Kaitangata, Otago, N.Z. .	19·61	37·25	39·41	3·73	—
Canterbury, N.Z.	24·09	21·61	50·12	4·18	—

Comp. $C_{11}H_{16}O_2$. C 78, H 10·5, O 10, S 0·5, Ash 1. A mixture of several resins with from 3 to 5 per cent. of succinic acid.

Pyr. In open tube fuses and emits white fumes of a pungent odour. In the open flame is consumed, leaving a slight residue. Only partially dissolved in alcohol, ether, and turpentine.

Loc. Found in irregular masses, from the size of a pea to that of a human head, in the oligocene strata of the Baltic region and their extension south-eastward into European and Asiatic Russia. It is a fossilized resin exuded by a conifer (*Pinus succinifer*) which occurs abundantly in the amber beds.

11. RETINITE (part *Copalite*). Massive, brittle. Fracture flat conchoidal.

H 2. G 1 to 1·1. Lustre bright resinous; by decomposition becomes dull to earthy. Colour yellowish white, greyish, dirty yellow, amber yellow, to brown. Transparent to opaque; often clouded.

Comp. C 73—83, H 7·5—12·5, O 6—16. Some varieties contain traces of succinic acid. Like amber it is probably a mixture of several resins.

Pyr. The Smeaton (Vic.) mineral is partly soluble in alcohol, ether, and caustic potash, more so in turpentine. Decomposed by hot nitric acid to a brownish-yellow waxy substance. In the open tube turns opaque white and swells up; on further heating fuses to a complete liquid, yielding grey fumes, oil, and tar. Heated on platinum foil is consumed without perceptible residue. Under the microscope shows abundant elliptical air vesicles.

Loc. Occurs in disseminated grains, irregular masses, and thin seams in brown coal and bituminous clays in most of the localities mentioned under "Brown Coal." In the "headings" of the deep leads of Smeaton, Ballarat, and Majorca, Vic. In the cretaceous coal-measures, Bay of Islands, N.Z. Obtained in artesian borings at Eldersly, Winton, Q. The great variability in the composition of retinite and copalite must be attributed to differences in the nature of the trees which yielded the resins. In the Ballarat district the trunks and seeds of a conifer (*spondylostrobus*) are found in great abundance in the sub-basaltic river drifts, and their presence affords a clue as to the probable derivation of the fossil resin in this instance.

12. TASMANITE (*Resinous Shale*). In minute scales and plates interlaminated in shale. Flat conchoidal fracture.

H 2. G 1·18. Lustre resinous. Colour reddish brown. Translucent.

Comp. C 79·34, H 10·41, O 4·93, S 5·32 (after deducting 8·14 per cent. of ash).

Pyr. In the open tube fuses imperfectly, and yields oil and tar. Burns with a smoky flame and empyreumatic odour, leaving a considerable solid residue. Not acted upon by alcohol, ether, or turpentine.

Loc. Disseminated through sandy shale in the mesozoic coal-measures of the Mersey Valley, Northern Tasmania.

This shale affords—Moisture 1·95, Volatile 26·75, Fixed carbon 7·20, Sulphur 2, Ash 62·05.

13. AMBRITE. Massive, brittle. Fracture conchoidal.

H 2. G 1·03. Lustre bright, resinous. Colour yellow to greyish. Transparent. Frictio-electric.

Comp. C 77, H 10·5, O 12·5.

Pyr. Burns with smoky flame, leaving a slight amount of ash. Insoluble in alcohol, ether, or turpentine. Decomposed by sulphuric acid.

Loc. North Island of New Zealand. A fossil resin from the Kauri pine (*Dammara australis*), buried forests of which occur at Papakura, and which still flourishes in the northern parts of the island.

BORON GROUP.

The characteristic luminous bluish-green colour which boric acid imparts to the outer blowpipe flame serves to determine the minerals of this group. Turmeric paper steeped in a solution containing boric acid assumes an orange-yellow colour, if the solution has been previously acidulated by just so much HCl as will suffice to redden blue litmus-paper.

14. SASSOLITE. Triclinic; minute hexagonal scales; also stalactitic. Perfect basal cleavage.

H 1. G 1·48. Lustre pearly. Colour white, but often coated yellow by sulphur. Transparent to translucent. Touch unctuous. Taste acid bitter.

Comp. $B_2O_3.\ 3\ H_2O = B(OH)_3$; hydrated boric acid.

Pyr. BB fuses at 1 with intumescence to a clear glass. In closed tube yields water. Soluble in water.

Loc. At the mouths of craters, fumaroles, and thermal springs, and around hot lakes. Italy, Aix-la-Chapelle, California, Andes. Essentially a volcanic product.

15. BORAX. Monoclinic; prisms with the faces shown in Fig. 87. Cleavage orthodiagonal perfect, prismatic imperfect.

H 2. G 1·72. Lustre vitreous to dull. Colour white, greyish, greenish. Streak white. Translucent to opaque. Fracture conchoidal. Taste slightly alkaline.

Comp. $Na_2O. 2 B_2O_3. 10 H_2O = Na_2B_4O_7. 10H_2O$; hydrous borate of soda.

Pyr. BB intumesces and fuses at 1 to a clear bead, which reacts alkaline with turmeric paper. Soluble in water. Placed in a porcelain dish, moistened with sulphuric acid, covered with alcohol and heated over the lamp, the ignited alcohol produces a vivid bluish-green flame.

Loc. In and around salt lakes and thermal springs. Thibet, California, Nevada, Canada, Ceylon.

Econ. The borax of commerce is largely manufactured from sassolite obtained at the hot lakes of Tuscany in Italy.

SULPHUR GROUP.

16. NATIVE SULPHUR. Orthorhombic; octahedral. Also massive, disseminated, stalactitic, and pulverulent. Crystals artificially produced by fusion are monoclinic. Cleavage octahedral indistinct.

H 1·5 to 2·5. G 2. Lustre resinous. Colour various shades of yellow to brown. Streak white. Translucent. Fracture sub-conchoidal. Semi-sectile. Frictio-electric.

Comp. Pure sulphur. Sometimes with an admixture of selenium, sulphide of arsenic, clayey and bituminous matter.

Pyr. F 1. Burns with a blue flame and emission of sulphurous acid. Not affected by acids; soluble in carbon disulphide.

Loc. Sulphur is either a product of sublimation, *i. e.* condensation of sulphurous acid vapours, or it results from the decomposition or oxidation of sulphuretted hydrogen into sulphur and hydrogen or sulphur and water respectively. The presence of H_2S whether in the gaseous form, as in solfataros, or contained in aqueous solutions, as in the so-called sulphur springs, generally leads to the deposition of sulphur. The white slime forming at the mouths of hepatic springs consists mainly of sulphur. Where the waters rise from, or percolate through, calcareous or baritic rocks they produce sulphate of lime (gypsum) and sulphate of barium (heavy spar). As a matter of observation the chief modes of occurrence of sulphur are either in volcanic regions or in association with gypsum. Organic substances reduce gypsum to calcium sulphide, which on being attacked by acids such as CO_2 or SO_3 (the latter derived from the decomposition of sulphides) yields H_2S, and this again by oxidation H_2O and S. This explains the frequent occurrence of gypsum alongside of sulphur in brown-coal seams. The same process of alteration has been noticed to take place in cabinet specimens some time after their removal from the mine. Frequently met with in metalliferous veins, where it results from the decomposition of sulphides, particularly pyrite, marcasite, galena, stibnite, etc. Also occurs as a sublimate deposited by burning-coal seams which are rich in pyrites.

In the volcanic region of Auckland, N.Z., especially White Island and Rotomahana.—On several of the volcanic islands of New Britain and the D'Entrecasteaux group off New Guinea.—At Ohaeawai, Auckland, deposited from hepatic springs.—Waitpinga, S.A., in cellular quartz in contact with barite.—Maldon, Castlemaine, Vic.; Peelwood, N.S.W.; Echunga, S.A., in auriferous quartz veins, from the decomposition of pyrite.—Costerfield, Vic., from alteration of stibnite.—Zehan and Mt. Reid, Tas., from galena.—Mt. Wingen, N.S.W., sublimate from the combustion of pyritous coal.

The most extensive sulphur deposits occur in Sicily, Naples, Iceland; Utah, California, and Washoe, U.S.A.; Chili, Hawai, Phillipines, etc.

17. SELENIUM. Hexagonal and monoclinic; allotropic in artificial crystals. Scaly, brittle.

H 2·5. G 4·4. Lustre metallic to sub-metallic. Colour steel to lead grey when slowly cooled after fusion; reddish brown with dark red streak when rapidly cooled.

Comp. Se.

Pyr. F 1. In closed tube gives dark yellow fumes which condense to black drops. In open tube yields brown vapours of peculiar radish-like odour, and a sublimate which is steel grey near, and red distant from, the assay. The sublimate on charcoal is steel grey and sub-metallic near the assay, and dull dark grey at a distance. In the presence of lead or antimony the sublimate on charcoal is cherry red. The properties here mentioned are those observed in the artificially-prepared metal.

Loc. Native selenium has been reported to occur as an accessory constituent in a mercury ore at Culebras in Mexico. With this exception selenium is known only in combination with other elements, chiefly in the form of selenides and sulpho-selenides. The following are among the more important selenium minerals.

Selen-Sulphur; a compound of sulphur and selenium in variable proportions. Reddish brown to orange yellow. Found in volcanic districts, *e.g.* Mediterranean, Japan, and New Zealand.

Clausthalite, PbSe. *Naumannite*, AgSe. *Berzelianite*, CuSe. *Lehrbachite*, (Pb, Hg_2)Se. *Tiemannite*, HgSe. *Onofrite*, Hg(S, Se).

ALKALI GROUP.

18. SAL-AMMONIAC. Isometric; octahedral with octahedral cleavage. Also encrusting, stalactitic, and earthy. Fracture conchoidal. Brittle.

H 1·5 to 2. G 1·53. Lustre vitreous. Colour white, but often tinged yellow by sulphur or chloride of iron. Taste acrid saline.

Comp. NH_4Cl, ammonium chloride.

Pyr. In closed tube volatilizes without previous fusion.

Mixed with potassium oxalate and heated in closed tube evolves ammoniacal fumes. Soluble in water.

Loc. The mode of its occurrence proves sal-ammoniac to be a product of sublimation. Found in fissures of active volcanoes, *e.g.* Vesuvius, Etna, Hecla, Sandwich Islands. Also near burning-coal seams, as at Newcastle; Scotland; St. Etienne, France; Duttweiler, Prussia.

19. NITRE (*Saltpetre*). Rhombic; frequently in six-sided prisms, each made up of three rhombic prisms. Also acicular, in tufts, and encrusting. Cleavage prismatic perfect. Fracture sub-conchoidal. Brittle.

H 2. G 2·1. Lustre vitreous. Colour and streak white. Translucent. Taste cool saline.

Comp. $K_2ON_2O_5 = KNO_3$, potassium nitrate.

Pyr. Fusible on platinum wire, colouring the flame violet. Heated on charcoal detonates and forms K_2CO_3. In a solution of $PlCl_2$ produced a yellow crystalline precipitate of potassium platinichloride. Soluble in water.

Loc. Occurs in superficial deposits in tertiary limestone and marl of Northern Africa, Egypt, Persia, etc. Abundantly produced by the action of decaying animal matter on calcareous soils.

Econ. The saltpetre of commerce is mostly artificially prepared.

20. TRONA (*Native Carbonate of Soda*). Monoclinic; prismal faces often horizontally striated. Cleavage prismatic perfect. Also fibrous and massive.

H 2·5 to 3. G 2·12. Lustre vitreous. Colour greyish or yellowish white. Translucent. Taste alkaline.

Comp. $Na_4H_2C_3O_9 + 3\ H_2O$ or $3\ Na_2O.\ 4\ CO_3.\ 5\ H_2O$; hydrated carbonate of soda.

Pyr. Reacts alkaline with turmeric paper. Colours flame yellow. In closed tube yields water and carbonic acid. Effervesces with acids; soluble in water.

Loc. At the margins of soda lakes, Africa, South America, California. Exflorescent near Mt. Arapiles, Vic.

21. NITRATITE (*Soda Nitre*). Hexagonal; rhombohedra like those of calcite; more commonly encrusting. Perfect rhombohedral cleavage.

H 2. G 2·25. Lustre vitreous. Colour white, frequently tinged yellow or brown by ferric oxide. Transparent. Taste cool, bitter.

Comp. Nitrate of sodium, $NaNO_3$; contains 10 per cent. more nitric acid than potash nitre.

Pyr. F 1; deliquescent. On charcoal deflagrates and forms $NaCO_3$. Flame coloration yellow. With turmeric paper gives alkaline reaction. Easily soluble in water.

Loc. Chili, California, New Mexico, in calcareous soils with rock-salt, mirabilite, and gypsum. The Chili deposits are of great regional extent and economic importance, the export of "Chili saltpetre" amounting to many thousand tons annually.

22. HALITE (*Common Salt, Rock Salt*). Isometric; generally in cubes, the faces of which are often depressed in the centre. Also granular and massive. Cleavage cubical perfect. Fracture conchoidal. Brittle.

H 2·5. G 2·1 to 2·5. Lustre vitreous. Colour water-clear or white; often tinged pale yellow, red, purple, or blue. Transparent to translucent. Taste saline.

Comp. Chloride of sodium, NaCl; frequently part of the Na replaced by Ca or Mg.

Pyr. F 1. Decrepitates. Flame coloration yellow. Fused with a bead of microcosmic salt which has been previously charged with oxide of copper, imparts an azure blue colour to the blowpipe flame. Placed alongside a grain of $FeSO_4$ or $CuSO_4$ on a clean silver plate and moistened produces a black spot of silver sulphide. Perfectly soluble in water.

Loc. The origin of rock-salt is in most cases traceable to sea-water. The ocean, covering an area of some hundred and thirty million square miles, with an average depth of 12,000 feet (about two and a quarter miles), represents a volume of nearly three hundred million cube miles. Since sea-water contains on an average 2½ per cent. of NaCl, the amount of salt held in solution by the ocean is probably not less than seven million cube miles, a mass far exceeding that of the whole of the dry land of the globe which lies above sea-level. When sea-water is evaporated the earliest deposit is Fe_2O_3 and $CaCO_3$. On further concentration $CaSO_4$ is precipitated, while NaCl does not begin to fall until the liquid is reduced to one-tenth of its original volume. Finally NaBr, KCl, MgCl, and $MgSO_4$, together with the remainder of the NaCl, are deposited. Wherever, therefore, rock-salt has been produced by the evaporation of sea-water, the floor of the deposit is made up of anhydrite or gypsum, while the roof is composed of the deliquescent salts mentioned. Any clayey matter which may have been suspended in the sea-water will be deposited simultaneously with the salts and form saliferous and gypseous marls and clays.

The geological range of salt deposits is extensive. The tertiary sediments along the southern coast of Australia, and extending inland up the Murray basin and into Central Australia, are in great part made up of saliferous and gypseous marls, clays, and sandstones. In the West Melbourne Swamp, the Koroit Swamp, and similar shallow lake-like depressions, only recently raised above the tide level, deposits of salt and gypsum are even now in the course of formation as the direct and visible result of the evaporation of salt brine. The well-known salt-mines of Wilitzka, near Cracow, in Austria, are situated in a great basin occupied by beds of gypsum, rock-salt, marls, and clays, the latter abounding in pliocene fossils. In the Carpathians rock-salt and gypsum occur in oligocene strata. In the Paris basin the uppermost eocene marine strata consist of saliferous and gypseous marls with marine fossils, while similar deposits extend into the next higher beds, which are of lacustrine origin. In the Jurassic strata of Westphalia extensive deposits of gypsum and rock-salt occur between massive bands of fresh-water limestone. In the Trias of Derby, Cheshire, and Somersetshire, in England, beds of salt, upwards of 100 feet in thickness, are associated with gypsum and marl. In many parts of Thuringia, Saxony, and the Hartz, the superior beds of the Zechstein (Upper Permian) are largely made up of rock-salt, gypsum, anhydrite, limestone, dolomite, and bituminous shale. At Stassfurt, in Prussian Saxony, the salt basin has a depth of 1155 feet; while at Sperenberg, near Berlin, a bore has pierced 283 feet of gypsum and anhydrite, and no less than 3769 feet of rock-salt. In European Russia, beds of salt with gypsum and marl constitute a considerable portion of the Upper Devonian strata. The oldest known salt deposits of proved commercial value occur in the Salina group of Upper Silurian age in the State of New York. Of still higher antiquity, but hitherto unworked, are the salt and gypsum beds forming part of the Lower Silurian sediments in the Salt Range, Punjaub, Upper India.

Halite has also been observed, in association with other chlorides, around volcanic craters and solfataras as the outcome of sublimation.

23. MIRABILITE (*Glauber Salt*). Monoclinic, mostly eight-sided prisms surmounted by pyramids; more commonly in downy films and encrusting. Cleavage orthodiagonal perfect.

H 1·5 to 2. G 1·48. Lustre vitreous. Colour white. Transparent to translucent. Taste cool, saline-bitter.

Comp. Hydrous sulphate of sodium, $Na_2SO_4 + 10 H_2O$.

Pyr. F 1. Yellow flame coloration. After fusion reacts alkaline with turmeric paper. In closed tube yields water. With soda forms an hepar. Readily soluble in water. In the aqueous solution barium chloride throws down a white precipitate of barium sulphate. On exposure to a dry atmosphere crumbles and becomes anhydrous.

Loc. Mirabilite frequently results from the action of decomposing sulphides upon minerals containing soda, particularly silicates such as mica and felspar. In this way it occurs efflorescent on the weathered faces of clay-pits at Lal Lal, Vic.—In adits driven in Silurian sandstone beneath basalt at Barfold, Vic.—At Chudleigh, Mersey River, Tas., on the floor of caves.—At Crystal Brook, S.A.—At the mouths of thermal springs, Austria, Italy.—At the margins of salt lakes, Chili, Utah.—As a volcanic product, Sicily, Sandwich Islands.

Econ. The glauber salt of the druggist is largely prepared artificially.

24. CRYOLITE (*Ice Stone*). Monoclinic, nearly square prisms, with the prismal faces often diagonally striated; macles common. Also massive. Cleavage basal perfect, prismatic imperfect. Brittle.

H 2·5. G 3. Lustre vitreous to pearly. Colourless, white. Often tinged reddish brown to black by ferric oxide. Transparent to opaque.

Comp. Fluoride of sodium and aluminium, $3\ NaF.\ AlF_3 = Na_3AlF_6$; containing 13 per cent. of aluminium.

Pyr. F 1. Yellow flame coloration. When placed in the open tube and exposed directly to the blowpipe flame, fumes of hydrofluoric acid are evolved which corrode the glass and impart a yellow colour to moistened Brazil-wood paper. On charcoal, after continued heating, a cake of alumina remains, which on being treated with cobalt solution, turns blue. Dissolves in H_2SO_4 with liberation of HF.

Loc. West Greenland, where it occurs in veins of granite traversing gneiss. The veinstone contains fluorite, cassiterite, and numerous metallic sulphides. Also met with to a subordinate extent at Yellowstone Park and Colorado, U.S.A.

Econ. Formerly much used in the preparation of metallic aluminium, for which purpose it is eminently suitable. The Greenland mines being unable to meet the demand for "aluminium ore," the raw material now chiefly employed is beauxite.

ALKALINE EARTHS.

The minerals of this group give, after ignition, an alkaline reaction (impart an orange-red colour to moistened turmeric paper).

25. WITHERITE. Orthorhombic, always hemitropes, having the twin planes parallel to the principal axis; usually six-sided pyramids with faces horizontally striated. Also botryoidal and massive. Cleavage macrodiagonal perfect. Fracture uneven. Brittle.

H 3·5. G 4·3. Lustre vitreous to greasy. Colour and streak white, inclined to yellowish and greyish. Transparent to translucent.

Comp. Barium carbonate, $BaCO_3$.

Pyr. F 2. Flame coloration yellowish green. Soluble with effervescence in HCl, the solution affording on the addition of H_2SO_4 a white precipitate of barium sulphate.

Loc. Witherite is one of the most soluble carbonates, 10,000 parts of water being capable of dissolving from 8 to 17 parts of the mineral. The readiness with which it undergoes change under the influence of meteoric agencies accounts for the circumstance that the mineral is so rarely met with in exposed situations. It is liable to be decomposed by alkaline and other sulphates, and aqueous solutions of these salts, as well as free sulphuric acid, convert witherite and barytocalcite into barite ($BaSO_4$). Crystals of barite containing a nucleus of witherite have been observed in galena veins in Cumberland. Sometimes these crystals are hollow, the witherite having been wholly or in part carried away in solution. In Lancashire lead-mines barite occurs at and near the surface, witherite at greater depth, indicating that the solution by which the change was effected passed from the surface downward. The reaction may be explained in this way: 1000 parts of witherite + 873 parts of gypsum produce 1182 parts of barite + 508 parts of calcite, while the small remainder of witherite is carried off in solution. Springsure, Q.

26. BARYTOCALCITE. Monoclinic; prisms elongated in the orthodiagonal direction; prismal faces vertically striated. Also massive. Perfect cleavage parallel to *m*. Fracture sub-conchoidal. Brittle.

H 4. G 3·65. Lustre vitreous to greasy. Colour white, grey, or yellowish. Streak white. Transparent to translucent.

Comp. Carbonate of barium and calcium, $BaCO_3$. $CaCO_3$, usually with a minute quantity of carbonate of manganese.

Pyr. F 6. Other reactions like those under witherite. The hydrochloric solution neutralized by ammonia gives with oxalic acid a white precipitate of oxalate of lime. Fused with soda usually affords a bluish-green mass of manganate of soda.

Loc. With barite forms the gangue of argentiferous lead veins at Ediacara, S.A., and in Cumberland, England.

27. BARITE (*Heavy Spar*, *Cawk*). Rhombic; generally in tabular prisms. Also globular, laminar to fibrous; sometimes stalactitic, granular, and earthy. Cleavage basal perfect, prismatic less perfect, diagonal imperfect.

H 2·5—3·5. G 4·3—4·7. Lustre vitreous. Streak white. Colour white, but often tinged yellow, brown, grey, or blue. Transparent, translucent to opaque. Some bituminous emit a fetid odour when rubbed.

Comp. Barium sulphate, $BaSO_4$, frequently with some lime, strontia, silica, argillaceous, and bituminous matter.

Pyr. Decrepitates when heated. F 3—4. Green flame coloration. With soda forms an hepar. Slightly soluble in HCl. In the dilute solution potassium chromate gives a yellow precipitate of $BaCrO_4$.

Loc. Occurs in thin tabular prisms, investing crystals of heulandite, in auriferous quartz veins at Maldon; also at Bairnsdale, Vic. On granite walls of quartz veins at Charters Towers, Q. In gold lodes at Mitchell's Creek and Captain's

Flat, N.S.W. Forming the gangue of lead and silver lodes at Ediacara, S.A.; Barrier Range, Carcoar, Braidwood, and Queenbeyan, N.S.W.; at Derbyshire and Cumberland, England; Freiberg, Saxony. Common in copper lodes of South Australia, *e.g.* Burra Burra, Blinman, Kapunda. With copper pyrites and gold at Mt. Lyell, Surrey Hills, and Pieman River, Tas. Similarly with copper ores at Cambalong and Bibenluke, N.S.W.

Econ. Ground up with linseed oil it is often used as an oil paint in the place of white lead.

28. STRONTIANITE. Rhombic; usually in prisms which are often acicular and divergent like aragonite. Also fibrous, globular, and granular. Cleavage prismatic perfect.

H 4. G 3·6—3·7. Lustre vitreous. Colour pale green, white, yellowish. Streak white. Transparent to translucent. Brittle.

Comp. Strontium carbonate, $SrCO_3$, usually with some lime.

Pyr. BB swells up but does not readily fuse. Red flame coloration. Dissolves with effervescence in cold HCl. In dilute solutions sulphuric acid gives a white precipitate.

Loc. With barite in lead lodes at Strontian, Argyle, Scotland; Saxony and the Hartz. Said to occur in an argentiferous lead vein of the Hampshire silver-mine, Tasmania.

29. CELESTITE. Rhombic, in modified prisms resembling those of barite. Also laminar, fibrous, granular, and earthy. Cleavage basal perfect, prismatic distinct, diagonal imperfect.

H 3. G 3·92—3·97. Lustre vitreous. Streak white. Colour white, bluish, rarely reddish white. Transparent to translucent. Fracture uneven to conchoidal. Brittle. Trichroic.

Comp. Strontium sulphate, $SrSO_4$, usually with some lime and strontia. The blue colour is probably due to phosphate of iron.

Pyr. F 3. Liable to decrepitate. Red flame coloration. With soda forms an hepar. Scarcely affected by acids, but soluble in a solution of 1 part potas. carbonate and 3 parts potas. sulphate (which distinguishes it from barite). Fusion with soda converts it into $SrCO_3$, which is soluble in HCl.

Loc. With sulphur in gypsum on Sicily; Lake Huron, U.S.A. Reported from the Gregory district, Q., and Wallaroo, S.A.

30. CALCITE. Hexagonal; chiefly the rhombohedron, scalenohedron, six and twelve-sided prisms, and six-sided pyramids. Frequently in combinations, both simple and complex, the number of distinct forms being upwards of two hundred and fifty, and exceeding that of any other mineral species. Also crystalline, granular, compact, earthy, and in various imitative forms. Cleavage rhombohedral, highly perfect. The dihedral angle of the fundamental rhombohedron is 105° 5′, and the angle over the edge formed by a basal plane and a rhombohedral face 135° 23′.

H 3; in some earthy varieties, as in chalk, the hardness is as low as 1, while in compact varieties, such as travertine, it rises to 3·5. G. 2·5 to 2·77. Lustre vitreous to dull. Colour usually white or colourless, but shades of yellow, red, brown, grey black, blue, purple, and green are not uncommon.

Comp. Calcium carbonate, $CaCO_3$; part of the calcium frequently replaced by Mg, Fe, Mn, and sometimes by Sr and Ba. The composition is also liable to be affected by the presence of mechanical impurities such as ferric oxide, chrome oxide, carbonaceous, bituminous, clayey and sandy matter.

Pyr. BB infusible, glows brightly, often decrepitates, and loses its lustre. Imparts a red colour to the flame, particularly when previously moistened with HCl. Dissolves readily, even when in large fragments, with effervescence in cold dilute acids. In hydrochloric solutions ammonium oxalate produces a white precipitate of oxalate of lime.

Loc. Carbonate of lime is, next to quartz, the most abundant mineral substance in nature. It forms independent rocks, viz. limestone, marble, chalk, ooze, and enters as an essential constituent in the composition of many sedimentary rocks, such as marl, calcareous sandstone, shale, and breccias. As a product of the decomposition of other minerals it takes part in the constitution of, or fills cavities in, such basic irruptive rocks as diorite, diabase, gabbro, basalt. Elsewhere it occurs in isolated concretionary masses —nodules, septaria—enclosed in an argillaceous gangue. Limestone, gypsum, as well as most calcareous silicates, *e.g.* the amphiboles, pyroxenes, garnets, zeolites, etc., are liable to be attacked by water charged with carbonic acid. From the solutions of bicarbonate of lime so produced organic substances, such as algæ and mosses, abstract part of the carbon dioxide, and so effect the precipitation of $CaCO_3$, often in a tufaceous form (calcsinter).

(*a*) *Iceland Spar;* a transparent, eminently cleavable variety, largely exported from Iceland, and employed in the construction of Nicol's prisms; has been met with at Pambula and Dubbo, N.S.W., and Angaston, S.A.

(*b*) *Dogtooth Spar;* crystallizing in acute scalenohedra, frequently with terminal planes of the rhombohedron. It yields more readily to decomposition than any other form of calcite. Fine crystals, frequently investing zeolites, occur in druses in the basalt of Melbourne and Kyneton, Vic.

(*c*) *Ferro-Calcite;* globular and club-shaped, of various shades of yellow, orange, and brown. Contains from 15 to 30 per cent. of the carbonates of iron, magnesia, and manganese, and so holds an intermediate position between calcite and ankerite. Abundant in the basalt of Melbourne, Ballarat, and Clunes, Vic.

(*d*) *Crystalline;* occurs in veins in hornblende rock at Biggenden, Q.; in serpentine at Orange, Dungog, and Gundagai, N.S.W.; in Hawksbury sandstone on the Cataract River, N.S.W.; in Jurassic shales, Otway district, Western

Port, and South Gippsland, Vic. Crystalline calcite forms the gangue of gold-bearing veins, either *per se* or in conjunction with quartz, at Gympie, Cloncurry, Charters Towers, and other northern gold-fields of Queensland; on the Thames and Coromandel gold-fields, N.Z.; Gulgong, Lucknow, Oaky, Bowman River, N.S.W. *Black calcite*, the colour due to carbonaceous matter, is found at Woolongong, Parkes, and Dayspring, N.S.W., and Hallet's Cove, S.A. *Satin spar*, a silky fibrous variety, at the Cataract Quarry, Launceston, Tas.

(*e*) *Marble;* cryptocrystalline, of various colours from white to black. White marble occurs at Wollondilly, Herberton, Rockhampton, Townsville, Warwick, and Gladstone, Q.; at Orange, Mudgee, Wellington Caves, and Cow Flat near Bathurst, N.S.W.; at Angaston, Ardrossan, Curramulka, Kapunda, Mt. Barker, Flinders Heights, and elsewhere, S.A.; at Caswell Sound and Milford Sound, N.Z. Mottled and veined marbles at Omeo, Vic.; crinoidal marble of Upper Silurian age at Anderson's Creek, Yering, and Heyfield, Vic. Slate-coloured marble at Marulan, N.S.W. Black marble at Arnprior, Shoalhaven. Purple and red marbles at Macleay and Tamworth, N.S.W.

(*f*) Granular and dense *limestone* occurs in beds and lenticular masses of lower palæozoic age at Yass and Tarawingee, N.S.W.; Gordon River, Tas., and Waralah Bay, Vic. In Devonian strata at Buchan and Biurti, Vic. In the coal-measures of New South Wales, Queensland, and Tasmania. Abundantly in tertiary and post-tertiary strata along the coast of Victoria, South Australia, and Western Australia. At Maria Island and Geilston Bay, Tas.

(*g*) *Stalactites* and *Stalagmites;* recent deposits on the roofs and floors of caverns, particularly in limestone country. Occur of singular extent and beauty in the Wellington and Jenola caves, N.S.W., and Mt. Gambier caves, S.A. Also in caverns at the Star River, Stanthorpe, and elsewhere in Queensland; on the coast between Port Campbell and Portland, Vic.; on the Hill River and Moore River, W.A.

31. ARAGONITE. Rhombic; occasionally in stout prisms, surmounted by domes or octahedra; more commonly in slender twin prisms consisting of two, three, or more individuals, the composition planes being those of the unit vertical prism. They thus often have the form of hexagonal prisms with or without reverting angles. Sometimes penetration twins which, owing to the unequal development of the individuals, present, as a rule, very irregular outlines. The striations, often noticeable on the prismal faces, are due to polysynthetic twinning. Cleavage brachydiagonal, rather distinct, usually producing striations on the basal plane. Also two imperfect cleavages, one parallel to the faces of the unit prism, the other parallel to the brachydome. Bundles of slender, divergent prisms very common. Also columnar, fibrous, stalactitic, encrusting, globular, and coralloid.

H 3·5—4. G 2·898—2·947. Lustre vitreous to silky. Colour white, inclined to greyish and yellowish. Transparent to translucent. Fracture sub-conchoidal. Brittle.

Comp. Calcium carbonate, $CaCO_3$, the same as calcite; $SrCO_3$, sometimes to the extent of 2·5 per cent., and H_2O, up to 0·4 per cent., are frequently present.

Pyr. Like calcite. BB, however, it crumbles to powder and does not decrepitate. The presence of Sr is revealed by an intensely red flame coloration.

Loc. Abundant in druses in the newer pliocene dolerite and basalt of Victoria, *e.g.* Richmond, Ballarat, Malmsbury; more rare in the older basalt, *e.g.* Western Port. In basalt at Lefroy, Waratah, Springfield, Tas.; Mudgee, Inverell, Vegetable Creek, N.S.W.; Thames and Collingwood, N.Z. In auriferous gravel drift immediately beneath the basalt lava at Ararat, Daylesford, Talbot, Taradale, Vic. In recent fresh-water limestone at Newstead, Vic. In limestone caves at Lob's Hole, N.S.W. In serpentine at the Peel River, Liverpool Plains, and Cudgegong, N.S.W. In mineral veins, associated with copper and iron pyrites at Wallaroo, Blinman, Armagh, Oratunga, Mt. Bold, S.A.

Whether carbonate of lime, in the process of separation from aqueous solutions, will assume the form and structure of calcite or of aragonite, depends on conditions which are by no means fully understood. From surface water and cold springs it is, as a rule, eliminated in the form of calcite; on the other hand, thermal springs and water contained in newly-ejected lava deposit it usually as aragonite. The inference that a high temperature is necessary for the production of aragonite is, however, contradicted by the circumstance that stalactites are sometimes made up of alternate layers of calcite and aragonite. By slow heat aragonite may be converted into calcite: thus in Vesuvian tuffs rhombic crystals have been observed, over an inch in length, which are externally transformed into calcite with distinct rhombohedral cleavage, while a nucleus of aragonite remains. Paramorphs of aragonite after calcite are perhaps of less frequent occurrence. In the basalt of the Alfredton quarries, at Ballarat, mammillary crusts of rhombohedral calcite are not uncommonly invested by downy coralline aggregates of *flos ferri*. Since the mean ratio of the densities of the two species is 2·9 : 2·6, the space originally occupied by the calcite is not completely filled by the aragonite, a circumstance which serves to explain the vesicular and drusy structure of the latter.

32. DOLOMITE. Hexagonal; rhombohedron, the polar angles frequently replaced by basal planes. The faces often curved, imparting a saddle shape to the crystal. Cleavage rhombohedral perfect. The fundamental (cleavage) rhombohedron has an angle of 106° 15′. Also granular and massive.

H 3·5—4. G 2·85. Lustre vitreous to pearly. Colour white, grey, yellowish, reddish, blue, brown to black. Transparent to translucent. Brittle.

Comp. $CaCO_3 . MgCO_3$, in the proportion of 54·35 to 45·65; part of the magnesia often replaced by iron and manganese.

Var. Pearlspar; crystallizes in small but well-developed rhombohedra, often saddle-shaped, and has an eminently pearly lustre.

Brown spar; yellowish white, liable to turn brown on exposure. Contains from 3 to 10 per cent. of $FeCO_3$, and thus occupies a position intermediate between normal dolomite and ankerite.

Dolomitic calcite and *dolomitic limestone* are granular or dense varieties, containing an excess of carbonate of lime. In the rock "dolomite," which occupies an important position among strata of upper palæozoic age, the amount of $MgCO_3$ falls not rarely to below 20 per cent., and is hence best described as a *magnesian limestone.* On the other hand, an excess of $MgCO_3$ gives rise to a compound which may be properly termed *calciferous magnesite.*

Pyr. BB behaves like calcite; ferriferous varieties turn brown to black. In large pieces it is but slightly acted upon by cold dilute acids; when powdered it dissolves with brisk effervescence in hot HCl. In the hydrochloric solution, that has been neutralized by NH_3, ammonium oxalate throws down a white precipitate of oxalate of lime. After filtering, the solution phosphate of soda produces a white precipitate of magnesium phosphate.

Loc. Constitutes the gangue of gold-bearing veins in serpentine, Jones Creek, near Gundagai, N.S.W. Granular, massive at Carwell, Shoalhaven. Occurs in crystalline granular aggregates with albite, pyrite, and quartz in gold lodes, Ballarat, where it also forms thin irregular veins in the adjoining pyritous slate. Blue crystalline dolomite with galena and calcite at Dundas; ferruginous at Mt. Pelion, Tas. The common variety has been noted at Victoria Ck., Rapid Bay, Amianth Place, Cornflower Hill, Mt. Barker, and Nichol's Nob, S.A.; Macarthur River, Northern Territory. Brown spar in saddle-shaped rhombohedra is found in auriferous quartz veins at the Band and Albion and neighbouring mines, Ballarat; New Chum Reef, Bendigo; Lisle's Reef, Maldon; Morning Star Reef, Wood's Point.

Magnesian limestone ($MgCO_3$ 39·12 per cent.) occurs at Moonee Ponds, near Melbourne. Also at Mt. Gambier, S.A. ($MgCO_3$ 15·2 per cent.), of a pleasing light red colour.

33. Ankerite. Hexagonal; in rhombohedra, also crystalline massive, sometimes botryoidal. Cleavage rhombohedral distinct.

H 4. G 3—3·1. Lustre vitreous to resinous. Colour white, brown, grey. Translucent to opaque.

Comp. Carbonate of calcium, magnesium, and iron in variable proportions, (Ca, Mg, Fe) CO_3, often with some manganese.

Pyr. BB blackens and becomes magnetic. Fused with soda frequently reacts for manganese (produces green manganate of sodium). In other respects like dolomite.

Loc. In lead veins, Umberumberka, N.S.W. In basalt, Melbourne, Barfold, Phillip Island, Vic. In quartz veins with native gold at Teetulpa, S.A. Crystalline at Gill's Bluff and Mt. Bold, S.A. In silver-lead veins, Mt. Bischoff, Heazlewood, and Dundas, Tas.

34. Apatite. Hexagonal; modified six and twelve-sided prisms, surmounted by truncated pyramids; hemihedral. Also fibrous, granular, reniform, compact, earthy. Cleavage prismatic rather distinct, basal indistinct.

H 5. G 3—3·2. Lustre vitreous to resinous. Colour bluish green, violet, greyish white, yellow, red, brown. Streak white. Transparent to opaque. On basal planes sometimes opalescent. Fracture sub-conchoidal. Brittle.

Comp. Calcium phosphate with some fluoride and chloride of calcium; $3\,Ca_3P_2O_8 + Ca\,(Cl, F)_2$, the percentage of the two latter constituents varying from 7·7 to 8·9. Frequently contains trifling amounts of ferric oxide and moisture.

Pyr. F 4·5 to 5. Moistened with sulphuric acid imparts a pale bluish-green colour to the blowpipe flame. The powder fused in closed tube with metallic sodium or magnesium and moistened with water evolves phosphoretted hydrogen. In the cold nitric solution ammonium molybdate gives a yellow granular precipitate of phosphomolybdate of ammonia. In the dilute nitric solution acetate of lead gives a white precipitate of phosphate of lead.

Loc. Crystallized in tin, iron, and other metalliferous veins traversing granite, gneiss, and crystalline schists, Mt. Bischoff, Blue Tier, Tas.; Cornwall, Saxony, Bohemia; Dunolly, Vic., in an auriferous quartz vein; Ravenswood, Charters Towers, Q.; Wallaroo, S.A. The crystalline massive variety (*phosphorite*) forms distinct veins and beds in strata of Laurentian and palæozoic age, *e. g.* in Canada, Scandinavia, Spain. With dolomite at Wog Wog, Lachlan; with graphite and quartz at head of Abercrombie River; also at the Clarence River, N.S.W. Amorphous and earthy in coprolite beds, and deposits of fossilized bones of vertebrates, *e. g.* at Skipton Caves, Vic., in guano on several of the islands in Bass Straits and off the coast of Western Australia. Coprolite beds and phosphatic concretions in the coal-measures of Scotland; in Triassic slates of Thuringia; in cretaceous strata in Cambridgeshire, England; and foremost in the later tertiary beds of South Carolina and Florida, U.S.A.

Very widely distributed, although only in crystals of microscopic size, in most eruptive rocks, from the ultra-acidic granites and quartz trachytes to the eminently basic dolerites and diabases. The crystals in these rocks are colourless, long, narrow, six-sided prisms (sometimes with small terminal pyramids), usually perfectly developed, and but rarely interfered with by other minerals. On the contrary, the most slender acicular crystals are seen to intersect most of the minerals with which they are associated, *e.g.* felspar, augite, hornblende; from which it is to be inferred that apatite is one of the first segregated minerals.

35. ANHYDRITE. Rhombic; broad rectangular prisms modified by planes of the macro- and brachydome. Also granular and fibrous. Cleavage macrodiagonal highly perfect, brachydiagonal perfect, basal distinct; the three sets of cleavage planes intersecting each other under right angles.

H 3. G 2·9. Lustre vitreous to pearly. Colour white, reddish, greyish, and bluish. Fracture splintery.

Comp. Calcium sulphate, $CaSO_4$.

Pyr. F 3, fuses to a white enamel. Flame coloration brick red. With soda forms an hepar. Soluble in HCl.

Loc. Associated with limestone, gypsum, and rock-salt, mostly in mesozoic and palæozoic strata, *e.g.* Prussian Saxony, Tyrol, Nova Scotia. Anhydrite readily absorbs moisture, and is hence liable to be converted into gypsum in situations where water has access to it. By laboratory experiments it has been demonstrated that if a saturated solution of calcium sulphate is subjected to a pressure of 150 lbs. per square inch, the precipitate formed consists of anhydrite and not of gypsum; from which the conclusion might be drawn that the natural formation of anhydrite has taken place under a considerable weight of superincumbent strata. The circumstance that anhydrite has not been met with in the comparatively shallow tertiary and recent deposits of gypseous clays and marls so abundant in Southern Australia may therefore be in a measure explained.

36. GYPSUM. Monoclinic; prisms modified by planes of the clinodome and pyramid; crystals often warped. Twins of the form shown in Fig. 139 common. Crystallized gypsum is called *selenite.* Also fibrous (*satin spar*); crystalline-granular to massive (*alabaster*); scaly and earthy. Cleavage clinodiagonal highly perfect, easily obtained, splendent; prismatic imperfect, produces fibrous surfaces; basal imperfect, but produces smooth surfaces; the second and third sets of cleavage planes intersect under an angle of 66° 14′, which represents the obliquity of the unit prism.

H 2. G 2·32. Lustre on clinodiagonal planes splendent, elsewhere vitreous, pearly, to dull. Colour white to colourless, greyish, yellowish, reddish, bluish white, red, brown to black. Streak white. Transparent to opaque.

Comp. Hydrated calcium sulphate, $CaSO_4 . 2 H_2O$.

Pyr. Yields water in closed tube; otherwise like anhydrite. Heated below fusing temperature and moistened with water is re-converted into a hydrate, forming a solid mass (*plaster of Paris*).

Loc. The formation of gypsum in nature takes place under one or other of the undermentioned conditions: (1) The action of SO_3 or SH_2 on sublimed CaCl, or on calcareous minerals such as labradorite, augite, zeolites. This, the least common mode of occurrence, is restricted to volcanic regions, *e.g.* White Island, Auckland, N.Z., where gypsum is found enclosing sulphur. Under similar conditions it is known to have resulted from the burning of pyritous coal-seams. With these exceptions gypsum is produced in the wet way. (2) The reaction of $CaCO_3$ on $MgSO_4$, such as would set in when lime-water meets with an aqueous solution of magnesium sulphate. (3) The action of sulphur springs on limestone, *e.g.* in some of the thermal springs of New Zealand. (4) The decomposition of pyrite into $FeSO_4$, which in turn decomposes $CaCO_3$, giving rise to the formation of sulphate of lime and carbonate of iron, *e.g.* at Point Addis, south of Geelong, in limestone and marl which are overlaid by pyritous sandy beds. (5) The hydration of anhydrite, as mentioned in the description of that species. (6) The evaporation of sea-water. The bulk of the deposits of gypsum (as well as rock-salt), of whatever geological age, is probably derived from this source. Thus in the fossiliferous marls, clays, and sands on the coast between Puebla and Point Roadknight; in blue oligocene clay, Schnapper Point; in tertiary strata at Warrnambool, Portland, the estuaries of the Yarra, Aire, and Gellibrand rivers. Abundant in the saliferous sands and clays occupying a great part of the Murray basin from Echuca to the sea, particularly in the neighbourhood of salt lakes in North-western Victoria, York Peninsula, Lake Torrens, Lake Eyres, etc. Similarly in the salt lake region of Western Australia.

In calcareous clays, Bulimba near Brisbane, Warrego district, Richmond Downs, Q.; Darling and Bogan rivers, Singleton, Lake Cobham, N.S.W.; Launceston, St. Marys, head of Mersey River, and Trial Harbour, Tas.

In the gossan of lodes at Charters Towers and Marengo, Q.; Silverton and Broken Hill, N.S.W.; Walleroo, Kapunda, Beltana, S.A.; Zehan, Tas.

In basaltic clay at Spring Plains, Campaspe River, Vic. In the carbonaceous sands and clays (so-called "headings") which rest upon a stratum of auriferous gravel, and are overlaid by lava, at Smeaton and Ballarat. In this case it may be inferred that the decomposing pyrites in the drift and the lime felspar in the overlying basalt have furnished the elements for the production of the selenite.

37. SCHEELITE. Tetragonal, usually in modified octahedra. Also granular, reniform, and massive. Cleavage octahedral distinct, diagonal imperfect.

H 5. G 6. Lustre vitreous. Colour white, yellowish, brownish, reddish. Streak white. Transparent to opaque. Fracture uneven. Brittle.

Comp. Tungstate of lime, $CaWO_4$, usually with a small amount of SiO_2 and Fe_2O_3.

Pyr. F 5. The micro. salt bead in OF is colourless, in RF impure green while hot and blue when cold. In the presence of iron in RF green hot, and brown to red brown cold. Decomposed by HCl with separation of yellow tungstic acid. The solution boiled with metallic zinc turns blue.

Loc. Occurs mostly in granite and crystalline schists, usually associated with quartz, wolfram, cassiterite, molybdenite, fluorite, topaz, apatite.

In auriferous quartz vein, Adelong, N.S.W. Similarly with wolfram and molybdenite at Maldon, Vic.; at the outcrop of the quartz vein the scheelite is decomposed to *tungstite*, a yellow pulverulent oxide of tungsten. Completely surrounded by cairngorm at Bradford Lead, Maldon. With tin ore in New England, N.S.W. With bismuth in amphibolite, Mt.

Ramsay; in garnet rock at head of Emu River, Tas. In crystalline schist at Lake Wakatipu, N.Z.

38. FLUORITE. Isometric; cube, combinations of cube and octahedron, macles of the form shown in Fig. 133. Also granular and massive. Cleavage octahedral perfect.

H 4. G 3·1—3·2. Lustre vitreous. Colour white, sometimes colourless, purple, green, yellow, brown. Streak white. Transparent to semi-translucent. Fracture sub-conchoidal. Brittle. Phosphorescent when heated.

Comp. Calcium fluoride, CaF_2.

Pyr. F 3. BB decrepitates and fuses to a white enamel. Red flame coloration. Fused with micro. salt in the open tube gives the reactions for fluorine described on p. 116. Boiled in H_2SO_4 yields vapours of hydrofluoric acid.

Loc. Occurs in veins, layers, and disseminated in crystalline schists and limestone; often forms the gangue of metalliferous veins. In tin lodes with wolfram in the Tinaroo district, Q. With cassiterite at Inverell, Cope's Ck., Vegetable Ck., N.S.W.—Beechworth, Vic.—Ben Lomond, Blue Tier, Mt. Bischoff; Mt. Ramsay, with bismuth, chalcopyrite, and quartz in hornblende rock; and Branxholm, Tas. In copper lodes at Moonta, Kapunda, Field River, S.A.; Wiseman's Ck., N.S.W. In limestone at Parara, S.A. In lead lodes at Woolgarlo near Yass, and Silverdale, N.S.W. Brock's Ck., Port Darwin.

39. BRUCITE. Hexagonal; rhombohedron usually truncated by basal planes. Crystals rare, commonly foliated or fibrous. Cleavage basal very perfect.

H 2·5. G 2·4. Lustre pearly, silky to waxy. Colour white, bluish, greyish, greenish. Streak white. Translucent to opaque. Sectile; in thin plates flexible.

Comp. Hydrate of magnesia, H_2MgO_2.

Pyr. BB infusible. In closed tube yields water, becomes dull and darker in colour. Heated with cobalt solution assumes a flesh-red colour. Easily soluble in HCl without effervescence.

Loc. Results from the alteration of serpentine, talc schist, dolomite, and other magnesian minerals and rocks. Beaconsfield, Heazlewood, Castray River, Tas.; Louisa Ck., Wellington, N.S.W.

Exposed to meteoric influence brucite absorbs CO_2, loses moisture, becomes earthy, and is converted into *hydromagnesite*, $3(MgCO_3 . H_2O) + H_2MgO_2$, as at Mt. Heemskirk, Tas. A further access of CO_2 and the total loss of water leads eventually to the formation of *magnesite* (*q. v.*).

40. MAGNESITE. Hexagonal; rhombohedron rare. Usually granular, oolitic, massive, compact. Cleavage rhombohedral, perfect.

H 4. G 3. Lustre vitreous to dull. Colour white, yellowish, greyish. Transparent to opaque. Fracture subconchoidal.

Comp. Magnesium carbonate, $MgCO_3$; part of the magnesia often replaced by protoxide of iron.

Pyr. Like dolomite, but gives no reaction for lime. Moistened with cobalt solution and ignited turns pink.

Loc. Occurs under similar geological conditions to brucite. In serpentine country at Islaport, Rockhampton, Toowoomba, Q. Similarly at Hood Mountain, Trial Harbour, Meredith Range, Heazlewood, and Dundas, Tas. At Flinders Range, Cunningham, Port Pirie, Oolabidnie Creek, Blinman, Mt. Lofty and Barossa Ranges, Amianth Place, Macdonnell Range, and Glen Osmond, S.A. At Kempsey, Scone, Gulgong, and elsewhere, N.S.W. In cretaceous strata, Northern Territory. Of later tertiary and recent formation at Mudgee and Bingera, in diamond-bearing drift, and Cunningham Diggings, N.S.W. On the Loddon River, near Newstead and Guildford, Vic. In kaolinitic clay at Bulla Bulla; in tertiary clays at Geelong, Bacchus Marsh, Western Port, Heathcote; in basaltic clay at Richmond and Collingwood near Melbourne, Majorca, Bendigo; concretionary in a fluccan traversing the Poverty Reef, Tarnagulla, Vic.

41. EPSOMITE. Rhombic; usually acicular prisms. Also fibrous, botryoidal, or encrusting. Cleavage brachydiagonal perfect.

H 2. G 1·75. Lustre vitreous to dull. Colour and streak white. Transparent to translucent. Taste saline-bitter.

Comp. Hydrous magnesium sulphate, $MgSO_4 + 7\ H_2O$, generally with some protoxide of iron and manganese, sometimes to the extent of 3·5 per cent.

Pyr. BB on charcoal melts with ebullition to a white mass which is not further fusible, and when moistened with cobalt solution and re-heated turns pink.

In closed tube yields water (50 per cent.) which reacts acid (reddens blue litmus-paper). Readily soluble without effervescence in acids and water. In the aqueous solution BaCl throws down a white precipitate of barium sulphate. Carbonate of soda gives a white precipitate of sodium sulphate.

Loc. Epsomite is held in solution in many spring and mine waters, from which it is deposited on the surface or in rock fissures. Efflorescent in caverns in basalt at Skipton and the Wannon Falls, Vic.; Barabool Hills, Cape Otway, Bacchus Marsh. On walls of mineral veins and in mine excavations at Clunes, Maldon, Lal Lal. Frequently proceeds from the decomposition of gypsum or pyrites in the presence of magnesian minerals, *e.g.* Hawksbury Caves, N.S.W.; in minute but well-developed crystals at Dabee and Mudgee; with alum in caverns of the coal-measures at Cullen Bullen, Wallerawang, Icely, Pye's Ck., Turon, Manero, N.S.W.—Dromedary Mountain, Upper Lake River, Exton, and Chudleigh, Tas.

42. STRUVITE. Rhombic; square prisms modified by planes of the pyramid; eminently hemimorphous, the faces of opposite sides of the crystal being as a rule of different shape. Cleavage basal perfect.

H 2. G 1·7. Colour yellowish or brownish white. Lustre vitreous to dull. Translucent to opaque. Brittle.

Comp. Hydrous phosphate of magnesia and ammonia, $NH_4Mg_2P_2O_8 + 12H_2O$, the percentage ratio being P_2O_5 29·0, MgO 16·3, NH_4 10·6, H_2O 44·1 = 100.

Loc. Struvite is formed when putrefaction of animal exuviæ takes place in the presence of mineral substances containing magnesia. Thus it occurs with other ammonia salts in thick deposits, which seem entirely made up of the excrements of bats, on the floors of caves in volcanic rock at Mt. Widderin, near Skipton. Similarly in a cavern under the falls of the Wannon River, near Hamilton, Vic. Found also in guano on the coast north of Capetown, South Africa.

ALUMINIUM GROUP.

The minerals of this group yield with cobalt solution an azure-blue mass. In making this test the assay is first strongly heated in the blowpipe flame, then moistened with cobalt solution, slowly dried, and finally ignited in a pure oxidizing blast. If necessary the substance is previously powdered and moistened with a little water; the paste is spread on platinum foil and fritted into a cake until it is sufficiently coherent to be grasped in the forceps.

43. **KALINITE** (*Native Alum, Potash Alum*). Isometric; octahedra usually in twins. Natural crystals rare; commonly fibrous, encrusting, or earthy.

H 2. G 1·75. Lustre vitreous. Colour and streak white. Transparent to translucent. Taste sweetish astringent.

Comp. Hydrous sulphate of alumina and potash, $K_2SO_4.Al_2SO_6 + 24\ H_2O = K_2Al_2S_4O_{16} + 24\ H_2O$.

Pyr. BB fuses at 1 to a frothy infusible mass, giving the violet flame coloration due to potash. Yields water in the closed tube. With soda forms an hepar. Easily soluble in water. In the aqueous solution BaCl gives a white precipitate of barium sulphate.

Loc. Efflorescent on shales and slates (so-called alum slates), where it arises from the action of oxidized pyrites on the silicate of alumina, which is the chief constituent of these argillaceous rocks. Thus at Steiglitz, Werribee Gorge, near Bacchus Marsh, Vic. In coal-measures sandstone, Woolongong, N.S.W. Also occurs as a volcanic product, *e.g.* Sicily.

Econ. The bulk of the alum of commerce is artificially produced.

44. **ALUNOGEN.** Monoclinic; six-sided tabular prisms. Generally fibrous, massive, encrusting.

H 2. G 1·7. Lustre vitreous to silky. Colour white, reddish, yellowish. Translucent. Taste sweetish astringent.

Comp. Hydrous sulphate of alumina $Al_2S_3O_{12} + 18\ H_2O$; frequently with a small amount of ferric oxide, magnesia, silica, etc.

Pyr. Like kalinite, but does not react for potash.

Loc. Occurs under the same geological conditions as alum. Exflorescent on shale in the coal-measures at Dabee; Wallerawang, mouth of Shoalhaven River, Mt. Wingen, Capertree Creek, N.S.W.—Blue Tier near Beaconsfield, Alum Cliff near Chudleigh, Bridgewater, St. Marys, Tas.

45. **ALUNITE.** Hexagonal; rhombohedra. Also fibrous and pulverulent. Usually granular massive. Cleavage basal distinct.

H 3·5 to 4. G 2·58—2·75. Lustre of crystals vitreous, otherwise silky or dull. Colour white, greyish, reddish. Streak white. Transparent to opaque. Fracture sub-conchoidal to earthy. Brittle.

Comp. Hydrous sulphate of alumina and potash, $K_2SO_4 . 3\ (Al_2O_3SO_3) + 6\ H_2O = K_2Al_6S_4O_{22} + 6\ H_2O$.

Pyr. BB infusible; decrepitates. In closed tube yields water. With soda forms an hepar. Soluble in sulphuric acid.

Loc. From its mode of occurrence seems to be essentially a volcanic product, resulting from the action of SO_2 on aluminous minerals. Found in trap rock at Bulladelah, Port Stephens, N.S.W., where it has been extensively quarried and used in the manufacture of alum, which, being free from iron salts, is of a superior quality. Also in basalt at Magnet Hill, near Gisborne, Vic.

46. WAVELLITE. Rhombic; prisms surmounted by domes. Crystals rare; usually globular, botryoidal, or mammillary, with radiating structure; also encrusting. Cleavage prismatic perfect, brachydiagonal distinct.

H 3—4. G 2·33. Lustre vitreous to resinous. Colour green, greenish white, white, yellow, grey, to black. Streak white. Translucent to opaque.

Comp. Hydrous phosphate of alumina, $3\ Al_2O_3.\ 2\ P_2O_5.\ 12\ H_2O$; frequently with some ferric oxide, fluorine, lime, silica, etc.

Pyr. BB infusible, swells and liable to split up into fibres. In closed tube yields water (27 per cent.). Flame coloration green (P_2O_5), enhanced by moistening the assay with sulphuric acid. Powdered and fused with magnesium or sodium in the closed tube, then moistened with water, evolves phosphoretted hydrogen. Soluble in HCl and KHO. In the hydrochloric solution NH_3 affords a white flocculent precipitate. In the potassic solution, previously rendered acid by an excess of HNO_3, molybdate of ammonia throws down a yellow granular precipitate.

Loc. In druses and on joints in slate and other argillaceous rocks. Brisbane, Q., in fissures of weathered felsite. Mudgee, in pebbles of a diamond-bearing conglomerate. Bacchus Marsh, Vic., on quartz. Landsfield, in Silurian slate. Gawler River, S.A., in gneissoid rock. In clay slate at Back Ck., Forth River, and Mt. Bischoff; in amphibolite at Mt. Ramsay, Tas.

A botryoidal colourless mineral, qualitatively related to wavellite, but having a specific gravity under 2, occurs encrusting the walls of a galena vein in the Mt. Zeehan Co.'s mine, Tas. It has been referred to the species *evansite* from Hungary.

47. TURQUOIS. Amorphous; reniform, botryoidal, stalactitic, encrusting.

H. 6. G 2·7. Lustre waxy. Colour azure blue to sea green. Streak white, or lighter than the colour. Sub-translucent to opaque. Fracture sub-conchoidal.

Comp. Hydrous phosphate of alumina, $2\ Al_2O_3.\ P_2O_5.\ 5\ H_2O$; with from 1·5 to 5·3 per cent. of CuO, to which the mineral owes its colour. Frequently contains some FeO or Fe_2O_3.

Pyr. BB infusible, but becomes vitreous and turns brown. Moistened with HCl tinges the flame at first azure blue (CuCl), subsequently emerald green, thus masking the colour due to P_2O_5. Fused with micro. salt gives copper reaction in both flames. In other respects behaves like wavellite.

Loc. Forms veins in clay slate in Persia, whence the finest-coloured turquois used in jewellery is obtained. Similarly at Kiewa River, in the Ovens District, Vic., in altered Silurian slate. Also occurs in Silesia and Saxony, but the mineral is of less pure colour and usually cloudy or mottled.

48. LAZULITE. Monoclinic, usually octahedral. Also massive. Cleavage prismatic, indistinct.

H 5—6. G 3·1. Lustre vitreous. Colour azure blue. Streak white. Translucent to opaque. Fracture uneven. Brittle.

Comp. Hydrated phosphate of alumina and magnesia, with part of the magnesia usually replaced by protoxide of iron, $(MgO, FeO)H_2O,\ Al_2O_3.\ P_2O_5$.

Pyr. BB infusible, but swells, crumbles, and becomes white. Further treated with cobalt solution turns blue. Reacts for phosphoric acid. Yields moisture in closed tube. With borax gives iron reaction. Not affected by acids.

Loc. In thin veins and lenticular patches in clay slate; crystallized in iron lodes. Styria, Sweden, Georgia, U.S.A.

49. MONAZITE. Monoclinic; hemimorphous, narrow

prisms with domes and octahedral planes. Cleavage basal, very perfect.

H 5—5·5. G 4·9—5·2. Lustre vitreous to resinous. Colour brown, reddish and yellowish brown. Translucent to opaque. Brittle.

Comp. Phosphate of cerium, lanthanum, thorium (Ce, La, Th)$_4$P$_2$O$_8$, usually with some didymium, alumina, etc. An analysis of the Vegetable Creek monazite afforded Mr. W. A. Dixon—P_2O_5 25·09, CeO 36·64, LaO and DiO 30·21, ThO 1·23, Al_2O_3 3·11, SiO_2 3·21 = 99·49. Frequently contains also MnO, CaO, SnO_2, etc.

Pyr. BB infusible, becomes grey. Reacts for phosphoric acid. The saturated borax bead is in OF orange yellow while hot, and citron yellow when cold; in RF colourless, but becomes enamel white by flaming. In the presence of much didymium the bead assumes a faint rose-red colour in RF.

Loc. Occurs in granite or granitic detritus. Vegetable Creek, N.S.W., in stanniferous granite; Ural and Finland, Russia; Bohemia in granitic rocks. In auriferous gravel and sand at Pinch Swamp Creek, Eastern Gippsland, Vic.; similarly in North Carolina, U.S.A.

SILICA GROUP.

Silica is the most widely-distributed chemical compound in the mineral kingdom, and its formation in nature is due to a variety of processes, chief of which are—(1) precipitation from aqueous solutions, such as waters circulating through siliceous rocks, thermal springs, etc., aiding in the production of vein quartz, quartz sinter, geyserite. (2) To hydro-plutonic agency, *i. e.* the action of super-heated steam on fused or partially fused silicates, as in granite and crystalline schists. (3) To secretion of aquatic plants and animals, *e. g.* jasper, tripolite. (4) To separation from a molten magma, *e. g.* tridymite in trachytic lava. It is improbable that quartz, in whatever situation, is produced by actual fusion, and its presence in rocks of undoubted igneous origin may be accounted for, as just stated, by assuming separation to take place at the instant of solidification of the matrix. Microscopic examination of granite-quartz reveals the presence of an abundance of vesicles filled with water, as well as the total absence of glass, both which conditions strongly negative the pre-existence of a state of fusion. On the other hand, quartz which enters into the composition of felsite porphyry does contain some genuine (isotropic) glass, beside some, though not very numerous, fluid enclosures, thus indicating a partial fusion of the matrix. Lastly, in the case of trachyte, a rock which independent evidence tells us has been in a condition of complete fusion, the quartz which it harbours is to a great extent made up of glass, while it is practically free from water.

Silica occurs as—(1) a distinct rock-forming mineral, *e. g.* reef-quartz, quartz schist, quartzite. (2) An essential constituent of crystalline rocks, such as granite, felsite porphyry, dacite, and of fragmentary rocks, such as sandstone, gravel, conglomerate. (3) An accessory constituent in rocks, *e. g.* diorite, diabase, trachyte. (4) Concretionary masses, such as flint, jasper, agate, opal.

The minerals of this group are infusible in the blowpipe flame. The powder mixed with soda in equal parts, and heated on platinum wire, fuses with effervescence to a colourless glass. With borax melts slowly to a clear glass. Silica is practically insoluble in microcosmic salt: this characteristic reaction is best seen when the flux is melted in a platinum-wire loop and the assay introduced in the form of an angular fragment (not of powder).

50. QUARTZ. Hexagonal; six-sided prisms, surmounted by prisms or rhombohedra. Alternate lateral solid angles often replaced by tetartohedral planes. Faces of the prism horizontally striated. Often in groups with only the pyramids projecting. Macles common, particularly penetration twins. Also cryptocrystalline, granular, and massive.

H 7. G 2·5—2·8. Lustre vitreous to resinous; adamantine to dull. In the pure state colourless, but owing to foreign admixtures assumes all colours. Streak white, or lighter than the colour. Fracture conchoidal to sub-conchoidal. Tough to brittle, sometimes friable.

Comp. Silica, SO_2; often with iron and other metallic oxides.

Pyr. Insoluble except in hydrofluoric acid.

Var. A. **Crystallized.**

(*a*) *Rock Crystal;* colourless, adamantine, transparent. Occurs in mineral veins and in waterworn pebbles on most of the mining fields of Australasia. Perfect double hexagonal pyramids with the intervening prism almost entirely suppressed are common in the valley drift of the Dundas Range between the Wannon and Glenelg rivers: also in a decomposed felsite dyke at Bayntons, north of Kyneton, Vic.

(*b*) *Amethyst;* purple or violet, the colouring agent being probably oxide of manganese. Usually found in granite country. Logan River, Mackay, Q.; Bathurst, Twofold Bay, Dubbo, Glen Elgin, N.S.W.; Beechworth, Maldon, Vic.; Wallaroo, Point Riley, S.A.; Moorina, Blue Tier, Emu River, Tas.; Rakaia Gorge, Canterbury, N.Z.

(*c*) *Rose Quartz;* rose pink, coloured possibly by oxide of titanium. New England; Maldon; Montacute Mine, Cunningham, S.A.; West Coast, Beaconsfield, Moorina, Tas.

(*d*) *Citrine* (*False Topaz*); yellow to brownish yellow, the colour of topaz. Usually in waterworn pebbles in the gold and tin drifts. Herberton, Q.; Bathurst, N.S.W.; Ararat, Maldon, Vic.; Cooper's Ck., Lake Eyre district, S.A.; Mt. Cameron, Blue Tier, Moorina, Tas.

(*e*) *Milky Quartz;* the milky appearance is shown under the microscope to be due to the presence of innumerable vesicles filled with water. Fine groups of crystals occur at Foley's Reef, Peel River, N.S.W.; Burra Mine, Ballarat; Wallaroo, The Peake, S.A.; Mt. Zeehan, Tas.

(*f*) *Cairngorm* (*Smoky Quartz*); smoky brown to brownish black, the colour apparently imparted by titanic oxide. Usually met with in granite country. Toowoomba, Stanthorpe, Q.; New England, Bathurst, N.S.W.; Beechworth, Maldon, Lal Lal, Talbot, Vic.; Wallaroo, Angaston, Cornflower Hill, S.A.; Flinders Island, Blue Tier, Tas.; Southern Cross, Yilgarn, Lake Austin, W.A.

B. **Crystalline** or **massive.**

(*g*) *Quartz Rock;* abundant in veins and "reefs" throughout the metalliferous regions of Australasia; in bedded masses Barrier Range, N.S.W., in palæozoic strata; Grampians, Vic., in Triassic sandstone; coast south-west of Puebla, Vic., in oligocene strata.

(*h*) *Sacheroid* (*Sugary*) *Quartz;* of granular texture induced by contact metamorphism, as shown in the neighbourhood of intrusive dykes, lava floes, etc. Gong Gong near Ballarat, Maldon, Taradale, Vic.

(*i*) *Quartzite;* is in most cases an altered sandstone, indurated by infiltration of silica, which has been deposited upon the individual quartz grains, and so aided in preserving the original granular structure. Where the original sandstone contained much cementing material, such as clay or lime, the latter has been replaced by silica, and so has given rise to independent patches of silica among the granular aggregates. The quartzites of the metamorphosed Silurian strata of Victoria generally exhibit these two forms of silica. In some localities, *e.g.* at Southern Cross, W.A., there is a third kind, viz. colloid and even opaline silica present. Elsewhere, *e.g.* Lake Austin and Nannine, W.A., the deposited silica is essentially chalcedonic. Some quartzites are, however, derived from slate in which silica has been more or less completely substituted for the argillaceous base, producing a laminated, and even foliated, variety (*quartz-schist*), common in the altered palæozoic sediments in many parts of Australia. Lastly, there is evidence to show that in some cases quartzite owes its origin to limestone or dolomite through substitution of silica for the carbonates. Under these conditions a passage of quartzite into chert can generally be recognized, and the material not unfrequently contains rhombohedral cavities. Such rocks have been described from Arkansas, U.S.A., under the name of *novaculites*, technically known as "Arkansas stone," or "hone stone." Common in altered Silurian, Maldon, Dunolly, Moorabool River east of Meredith; along Williamson's Ck., south of Buninyong, a quartzitic paste forms the cementing medium of a pliocene quartz pebble conglomerate; forming the gangue, near the surface, of auriferous veins in the Murchison district, W.A.; extensively developed in the crystalline schists of south-western Otago, N.Z.

(*j*) *Prase;* green quartz which owes its colour to oxide of iron or chromium. Cape River, Stanthorpe, Q.; Pambula, N.S.W.; Mitta Mitta River, Heathcote, Specimen Gully near Castlemaine, Vic.; Lake Sorell, Tas.; Gawlor Downs, Canterbury, N.Z.

(*k*) *Quartz Sinter;* cavernous, spongy, porous; deposited from aqueous solutions at the mouths of springs or in the gossan of metalliferous veins. Mt. Morgan, Q.; Broken Hill, N.S.W. Common in the caps of auriferous quartz reefs, Ballarat East (the "mouse-eaten" quartz of the miner); Teetulpa, S.A.; Beaconsfield, Pieman, Tas. In trachyte country, Monaltrie, N.S.W.

C. **Cryptocrystalline** or **colloid.**

(*l*) *Chalcedony*, usually bluish white, also white, grey, pale brown, blue, or black. Perhaps always mixed with some opal. Botryoidal, mammillary, stalactitic. Occurs in veins, sometimes constituting the whole gangue; also in concretions and rolled pebbles. Hodgkinson, Cloncurry, Springsure, Mackay, Q.; Dubbo, Wellington, Mt. Wingen, Maitland, Carcoar, Gulgong, N.S.W.; Beechworth, Landsborough, Clunes; in basalt, Phillip Island, Keilor, Sunbury, Vic.; Angaston, Wallaroo, Flaxman's Valley, Mt. Barker, Gawler, S.A.; Flinders Island, Beaconsfield, Lake Sorell, Dundas, Tas.; Mt. Somers and Clent Hills, Canterbury, N.Z.

Enhydros (water stones) are unsymmetric polyhedral crystals, probably casts, of a light brown chalcedonic quartz, frequently hollow and filled with water or mineral solution. Found in kaolinitic clay, Spring Ck., near Beechworth.

(*m*) *Carnelian;* red to brownish red. In drift pebbles Western Queensland, Barcoo and Lake Eyre district; Maitland, Wellington, Inverell, Tweed River, N.S.W.; Beechworth, Upper Yarra, Upper Murray, Vic.; Flinders Island, Swansea, Tas.

(*n*) *Chrysoprase;* coloured apple green by oxide of nickel. Heazlewood, Tas.; New Caledonia.

(*o*) *Agate;* reniform masses made up of concentric layers varying in colour, thickness, and porosity, and presenting in section differently-coloured bands, annular, waviform, or zigzag in outlines (eye-agate, ring-agate, fortification-agate, ruin-agate). Sometimes the layers consist alternately of chalcedony, carnelian, quartz, amethyst, etc. Also clouded, dendritic, and mossiform. Fills cavities in melaphyre and other eruptive rocks; more commonly occurs as rolled pebbles; so over a great part of Western Queensland and Central Australia, probably derived from the degradation of the Desert Sandstone. Etheridge, Burnett, Mackay, Q.; Scone, Inverell, MacIntyre, Gwydir, Hunter, Cope's Ck., N.S.W.; Berwick, Princetown, Vic.; Leven, Forth, Swansea, Lake Sorell, Flinders Island, Tas.; exceptionally in basalt at Kiama, and in diorite at Mittagong, N.S.W.

(*p*) *Onyx;* a variety of agate, in which the colours of alternate bands are in strong contrast, usually black and white, or black, brown, and white, and the layers instead of being concentric or curved are arranged in even parallel planes. It is these properties which render the stone suitable for cameos. Springsure, Q.; Baw Baw Range, Beechworth, Vic.

(*q*) *Heliotrope;* a leek-green chalcedony with blood-red speckles of jasper. Not common; has been reported from Stuart's Ck., S.A.

(*r*) *Jasper;* colour usually some shade of yellow or red; also grey, bluish, and greenish; often striped. Less translucent and of duller lustre than agate. Reniform and orbicular concretions, as well as waterworn pebbles, occur in most of the localities mentioned under agate. Sometimes forms the cement of conglomerates and breccias, as at Heathcote, Vic.

(*s*) *Flint;* grey, brown to black. Usually contains some alumina, lime, etc. Fracture eminently conchoidal; edges of fragments sharp. Occurs concretionary in the tertiary fossiliferous limestone of Cape Otway, Warrnambool, Mt. Gambier, MacDonnell Bay.

(*t*) *Lydian stone* (*Basanite*, *Touchstone*); grey to black; usually contains some alumina, magnesia, oxide of iron, etc. Occurs in bands in altered palæozoic strata; also in rolled pieces. Mullian Range, Bathurst, N.S.W.; Beechworth, Cape Otway, in the bed of the Glenelg River south of Dergholm, Vic.; Lake Eyre district, S.A.; Whangarei, N.Z.

(*u*) *Hornstone;* yellow, grey, brown to black; horn-like lustre. A common product of contact metamorphism, particularly at the boundary of Silurian slate and granite. Springsure, Ravenswood, Mackay, Q.; Mt. Ararat, Maldon, Vic.; Western Tasmania.

The name *Chert* is often used comprehensively to include varieties of jasper, hornstone, and even flint. Chert forms subordinate layers throughout the coal-measures of Queensland and New South Wales; so at Mt. Victoria, Hartley, Illawarra, Lachlan.

D. **Endomorphous.**

(*v*) *Endomorphs proper*, *i.e.* crystallized quartz enclosing crystals of other minerals, *e.g. Schorl:* Murrumbidgee; Maldon, Superb Reef, west of Linton, Vic. *Chlorite:* Stratford Lodge, Coliban River, Grey Horse Mine, Ballarat East. *Asbestus:* Uralla, N.S.W. *Cassiterite:* Stanthorpe

Tinaroo; New England, N.S.W.; Blue Tier, Tas. *Actinolite:* Merrendee, N.S.W. *Molybdenite:* Goulburn, N.S.W.; Maldon, Vic. *Rutile:* Cope's Flat, N.S.W.; Moorina, Mt. Cameron, Tas. *Idocrase:* Dusky Sound, Otago, N.Z. Octahedral crystals of gold in rock crystal have been noted in several Victorian localities, *e.g.* Wood's Point, Heathcote, Redbank; also at Nannine, W.A.

(*w*) *Ferruginous quartz*, coloured red by ferric hydrate usually deposited on joints and in fine cracks. Frequently met with on the gold-fields.

(*x*) *Cat's Eye;* a green quartz traversed by parallel layers of asbestus, which gives it a monochromatic opalescent lustre. Beechworth, Upper Yarra.

(*y*) *Aventurine;* yellow to brown; with disseminated minute scales of mica, and usually traversed by numerous cracks. Forms subordinate layers in mica schist, *e.g.* Ural, Styria, Spain, Egypt. Reported from Western Australia.

E. **Pseudomorphous.** Gelatinous silica is peculiarly adapted to mould itself upon, and so preserve the form of, organic substances. Thus in cretaceous and tertiary strata jasper frequently constitutes the petrifying medium of sponges, flint that of foraminifera, amorphous quartz that of leaves and other plant remains.

(*z*) *Silicified wood*, a pseudomorph of quartz after wood, the fibrous texture of which is more or less perfectly preserved. Common in the coal-measures sandstone of Queensland, New South Wales, and Tasmania. In mesozoic sandstone, Otway district, South Gippsland, Bacchus Marsh, Vic. Also found at Darling Downs, Q.; Inverell, N.S.W.; Daylesford, Vic.; Macquarie Plains, Tas.; Waikawa, Otago, N.Z.

51. TRIDYMITE. Hexagonal; minute six-sided tables, usually macles made up of three individuals; the plates often piled upon and overlapping each other. Cleavage basal, perfect.

H 7. G 2·2—2·3, the density of opal rather than of quartz. Lustre vitreous. Colourless and transparent.

Comp. SiO_2, like quartz.

Occurs in cavities in trachyte, andesite, and allied acidic volcanic rocks. Has been artificially produced in zinc muffle furnaces.

Loc. Lyttleton, Christchurch, Rotorua, N.Z.

52. OPAL. Amorphous; concretionary, stalactitic, earthy.

H 5·5—6·5. G 1·9—2·3. Lustre vitreous, pearly, resinous to dull. Colour white and all colours, usually in light shades. Streak white. When pure, opalescent with a subdued play of colours. Transparent to opaque.

Comp. Hydrated silica, $SiO_2 + H_2O$, the amount of water varying from 2½ to 21 per cent. Often mixed with quartz or chalcedony.

Pyr. In the closed tube yields water and becomes opaque. For the most part soluble in a hot solution of potassa or carbonate of soda. Otherwise like quartz.

Var. (*a*) *Noble Opal;* milk-white with pleochromatic opalescence; usually green, pink, and red, or blue, green, and red. In decomposed amygdaloidal trachyte, Rocky Bridge Creek, Abercrombie River; in clayey ironstone, Wellington; White Cliffs near Wilcannia, Louisa Ck. near Forbes, Coroo, Bloomfield near Orange, N.S.W. In brown ironstone, Springsure; Barcoo, Bulloo River, Q.; Beechworth, Vic.

(*b*) *Fire Opal;* wine yellow to pink with brilliant fire-red reflections, and vitreous lustre. Bulloo and Barcoo rivers, Springsure, Q.; Wellington, N.S.W.

(*c*) *Common Opal,* including *Semi Opal;* milk-white, yellow, red, brown, or mottled. Semi opal is often striped. Lustre waxy; sub-translucent to opaque. Generally contains some Al_2O_3 and Fe_2O_3 as well as diffused quartz. Gympie, Glasshouse Mountain, Burnett and Logan rivers, Gregory district, Q. In basaltic country, Louisa Ck., Tambaroora, Uralla, Inverell, Trunkey, Homerule, Gulgong, Orange, Gundagai, N.S.W. In basalt, Richmond, Bacchus Marsh, Gisborne, Sunbury, Gelantippy in Gippsland; in porphyry, Wickliffe, Dandenong, Vic. Angaston, Amianth Place, Flaxman's Valley, Mt. Crawford, Flinders Range, S.A. Mt. Cameron, Hobart, Port Cygnet, Pieman, Macquarie Harbour, Tas. In mesozoic rocks, Coast Range in the western part of Western Australia.

(*d*) *Wood Opal*, opalized wood; the original fibre of the wood often retained, and the rings of growth marked by various shades of brown. Often met with in drift which is covered by lava. Springsure, Dawson River, Q.; Tambaroora, N.S.W. In auriferous gravel underlying basalt at Elevated Plains, north of Daylesford; Bass River, Vic.; Launceston, Hobart, Swansea, Flinders Island, Tas.

(*e*) *Hyalite;* colourless and transparent. Botryoidal and encrusting in dolerite, lining cavities in the rock, and sometimes coating crystals of zeolite and aragonite. Stanthorpe, Springsure, Cumkillenbar, Q.; Jordan's Hill, Cudgegong; Vegetable Creek, N.S.W. Common in the basalt of Ballarat, Learmouth, Ararat, Kyneton, Malmsbury, Vic.; Zeehan, Blue Tier, Tas.

(*f*) *Geyserite* (*Opal sinter*); stalactitic, spongy, coralloid, or capillary. Usually occurs at the mouths of thermal springs and in recent lavas; also in the gossan of veins. Tarawera, Rotorua, N.Z.

(*g*) *Tripolite* (*Randanite*, *Infusorial Earth*, *Kieselguhr*); white, chalk-like when pure; essentially made up of the frustules of *diatomaceæ*. Often distinctly laminated, the laminæ representing layers of growth. Impure varieties contain more or less clayey and sandy matter. The most extensive deposit in Australia occurs at Lillicur near Talbot, Vic.; it rests on basalt, and is sixteen feet in thickness. Similarly at Clunes and Eddington. At Cardigan, near Ballarat, a layer six feet in thickness of clayey tripolite rests on a gravelly stratum, and is overlaid by 200 feet of lava. Also occurs at Hepburn near Daylesford, St. Kilda, Ararat, Vic.; Tamworth, N.S.W.; Oamaroo, N.Z.; Oatlands, Tas.

ANHYDROUS SILICATES

AMPHIBOLE GROUP

53. **Amphibole.** Monoclinic; oblique rhombic prisms, mostly six-sided (Figs. 87, 88); when eight-sided the sides parallel to the orthodiagonal are usually short. Often in long thin blades (reedy), and thence passing into columnar and fibrous forms. Also crystalline granular and massive. Cleavage prismatic (parallel ∞P) perfect; the two sets of cleavage planes intersect each other under an angle of from 124° to 124° 30′, which is the angle of the fundamental prism. Also two imperfect pinacoidal cleavages, parallel to $\infty \bar{P} \infty$ and $\infty \not{P} \infty$, which intersect under right angles. The faces of the crystal, as well as the prismatic cleavage planes, usually longitudinally striated.

H 5—6. G 2·9—3·4. Lustre vitreous to silky. Colour green, brown, yellow, of various shades to black. Streak white or lighter than the colour. Translucent, rarely transparent; sub-translucent to opaque. Under the microscope strongly pleochroic. Fracture uneven. Tough.

Comp. Silicate of magnesia and lime in variable proportion; part of the silica often replaced by alumina, and part of the magnesia by protoxide of iron, $(Mg, Ca)Si_2O_6$ to $(Mg, Ca, Fe)Si_2O_8 + Al_2O_3$. The proximate percentage composition of the several species is indicated in the subjoined table—

	SiO_2.	MgO.	CaO.	FeO.	Al_2O_3.
Hornblende . . .	45—55	13—21	9—14	5—21	4—15
Smaragdite . . .	40—54	11—20	13—23	2—3	4—13
Actinolite	55—59	16—24	10—17	3—6	0—3
Tremolite	55—60	24—28	11—15	0—2	0—1·7
Nephrite	55—58	20—27	11—16	1—5	0—1·5
Asbestus	54—59	26—31	0—17	3—13	0—1·6

Pyr. F 3·5 to 6, the fusibility depending mainly on the percentage of iron; the varieties rich in iron fuse readily to a black magnetic slag. Difficultly acted upon by acids. Optical and other physical properties, as well as habitat, serve in most instances to identify the species.

Var. (*a*) *Hornblende;* crystallizes in short, stout, generally six-sided prisms. Colour dark green, brown to black. G 3·1—3·4. Occurs as an independent rock (amphibolite), as a regular constituent in syenite, quartzless porphyry, diorite, etc., and as an accessory constituent in basalt, porphyries, etc. Basaltic hornblende is almost black, is richest in iron, and has the highest specific gravity. Rocks containing hornblende generally afford magnetite on decomposition.

Loc. Charters Towers, Herberton, Springsure, Biggenden; in basalt, Endeavour River, Q.—Uralla, Tenterfield, Bendemeer, Cope's Ck., Tamworth, Vegetable Ck., Tallebung Hills near Forbes; Broken Hill, Barrier Ranges; with talc, calcite, and gold at Gundagai, N.S.W.—In granite, Moorabool River east of Lal Lal, Mt. Alexander, Heathcote; in basalt, Camperdown, Warrenheip, Smeaton Hill, Anakies, Phillip Island, Vic.—Macdonnell and Musgrove Ranges, Hale River, S.A.—Mt. Ramsay, Hampshire Hills, Dundas, Arthur and Savage rivers, Tas.—Yilgarn, Murchison, Albany, Northampton, Roeburn, Kimberley districts, W.A. —Baton River, Nelson, Dusky Sound, Otago, N.Z.

(*b*) *Smaragdite;* light grass green, in thin scales; probably an alteration product of diallage. Forms a constant constituent in certain eruptive rocks, notably some varieties of gabbro.

Loc. Canobolas near Dowagarang, County of Wellington; in a porphyry dyke at Molong Ck., Ashburton, N.S.W.

(*c*) *Actinolite;* long narrow prismatic crystals, often radiating, also fibrous and massive. Colour usually dark green, passing sometimes into greyish green. Forms an independent rock (actinolite schist), frequently associated with talc schist, chlorite schist, and serpentine.

Loc. Cloncurry, Q.—Mowembah, Trunkey, Merrendee, Bathurst, Lucknow, N.S.W.—Amianth, Flaxman's Valley, Wallaroo, Yudanamutana, Flinders Heights, S.A.—Hampshire Hills, Heazlewood, Forth River, Whyte River, south of Waratah, Tas.—Parapera, Collingwood, N.Z.

(*d*) *Tremolite;* crystals not common; usually fibrous. White or grey. Occurs in talc schist, limestone, dolomite; with quartz forms a rock, tremolite schist.

Loc. Cooma, N.S.W.; tremolite schist at Broken Hill, Barrier Range.—Maldon; east of Mt. Macedon, Vic.—Flinders Heights, Barossa, Flaxman's Valley, Victoria Ck., Yudanamutana, S.A.—Heazlewood, Waratah, Belvoir, Mt. Pelion, Tas.—Dusky Sound, Otago, N.Z.

(*e*) *Nephrite* (Jade); bright green to greyish green. Massive, dense, very tough.

Loc. Amianth Place, S.A.—Milford Sound, N.Z.

(*f*) *Asbestus.* In all the non-aluminous varieties of amphibole a tendency to ordinary fibrous structure is apparent. When this structure is fully developed the fibres are long, slender, and readily separated, and not rarely affect the flexibility and delicacy of flax or silk; the mineral is then called *asbestus.* The kind having the longest silky fibres is known as *amianthus;* the interlaced, matted, short-fibred varieties as *mountain leather* and *mountain bark.* The mineral chrysotile (*q. v.*), an hydrated magnesian silicate, likewise occurs in a finely fibrous condition, and as it is more commonly distributed it is largely sent into the market under the name of asbestus. It is easily fusible, while true asbestus is infusible or fusible above 5. Even the several kinds of amphibole-asbestus vary considerably in respect to composition and physical properties; hence the name "asbestus" can no longer be held as distinctive of a species, and its use in mineralogy is now generally restricted to the purpose of description, *e.g.* asbestiform tremolite, asbestiform chrysolite, etc.

Loc. Jones Ck. near Gundagai, Wiseman's Ck., Cow

Flat, Carcoar, Briar Ck. in serpentine country; in diorite at Gulgong, N.S.W.—Mountain bark, in fissures of Silurian clay slate overlaid by gravel drift, at Tarilta near Guildford, Vic.—Barossa, Port Lincoln, Gumeracha, Belvedere Range, Angaston (mountain leather), Flinders Heights, Macdonnell Range, S.A.—Whyte River, both asbestus and mountain bark, Heazlewood, Tas.—Dun Mountains, Nelson, N.Z.

54. **CROCIDOLITE.** Fibrous, asbestiform; the fibres possessed of great tensile strength. Also compact.

H 4. G 3·2. Lustre silky. Colour pale violet blue, green, brown with brilliant reflections. Translucent to opaque.

Comp. Silicate of iron, magnesia, lime, and soda, with basic water; approximately $(Fe, Mg, Ca, Na)_6Si_5O_{16}$, $2\ H_2O$.

Pyr. BB fuses at 3 to a black magnetic slag, and gives a yellow flame coloration. Not affected by acids.

Loc. Arkaba, Wirrawilka, Robertstown, S.A. The finest samples of this ornamental stone come from Griqualand, South Africa.

PYROXENE GROUP.

Pyroxene is the generic name of a number of species closely allied in crystallization and composition to the amphibole group. The geological range of pyroxene is, however, much more limited than that of the amphiboles. While the latter occur in rocks of every age and character, volcanic and plutonic, basic and acidic, pyroxene enters chiefly into the composition of the younger basic rocks.

55. **AUGITE.** Monoclinic; crystals usually of the form shown in Figs. 90 and 147; twins like Fig. 148 common. The prisms are generally eight-sided. Striation parallel to external faces of prism. Cleavage prismatic perfect, but less so than in hornblende; orthodiagonal cleavage distinct, basal imperfect. The prismatic cleavage planes intersect under 87° 5′, which is the angle of the proto-prism. This

being nearly a right angle, the cleavage prism of augite can be readily distinguished from that of hornblende, in which the angle is 124° 30′. Owing to the imperfect basal cleavage the outlines of augite crystals often appear under the microscope rough and curved, whereas the boundaries of hornblende crystals are usually sharply defined and rectilinear. In microscopic sections the crystals of basaltic augite are frequently seen to be pierced by colourless hexagonal prisms of apatite. Augite also occurs in thin tabular masses, granular, fibrous, and even asbestiform.

H 5—6. G 3·23—3·5. Lustre vitreous to pearly; rather more brilliant than hornblende. Colour leek green, greenish white, greyish green, brown to black. Under the microscope only feebly dichroic. Streak white or pale greyish green. Transparent to opaque. Fracture uneven. Brittle.

Comp. Silicate of lime, magnesia, and iron; part of the silica replaced by alumina, $[(Ca, Mg, Fe)_3O_9]$ (Si_3O_6, Al_4O_6).

Pyr. Like amphibole, from which it may be distinguished by its physical properties and habitat.

Loc. Forms an essential constituent of basalt, tufa, andesite, and other volcanic products; also occurs in diabase, serpentine, and more rarely in metamorphic rocks. Springsure and Gates' Look-out, Q.—Cameron's Ck., County of Hardinge; Newstead and Middle Cks., County of Gough; Guntawang, County of Phillip; Molong, and elsewhere, N.S.W.—In the tufa of Hepburn's Lagoon near Creswick, Smeaton Hill, Moorokyle, Buninyong, Learmouth, Mt. Wallace north of Steiglitz, Vic.—Mt. Gambier, S.A.—Emu Bay, and thence south to Waratah; St. Paul's Plains, Mt. Horror, Tas.—Antrim Plateau, W.A.—Tongariro, Ruapehu; Waipara, Canterbury, N.Z. The most perfect crystals observed in the Australasian area occur in the volcanic ash of Viti Levu, Fiji.

Var. Diallage. Cleavage orthodiagonal highly perfect. Colour bright green, and other shades of green; on cleavage planes often exhibits a yellow bronze-like semi-metallic lustre. H 4. Strongly doubly refracting. The perfect orthodiagonal cleavage, bright green colour, and inferior hardness distinguish this mineral from augite. Enters with labradorite into the constitution of a group of rocks called gabbro. Also occurs in talc schist and serpentine.

Loc. Bingera, Warialda, Kelly's Ck., Gwydir River, and Tamworth in serpentine; Locksley, N.S.W., in a copper lode.—Barabool Hills near Geelong and Mt. Wellington, Vic., in gabbro.—Amianth Place, Tanunda, S.A.—Dun Mountains, Nelson, N.Z.—Noumea, New Caledonia.

56. DIOPSIDE (*Malacolite*). Monoclinic; crystals and cleavage like augite; tabular, granular, and massive.

H 5·5. G 3·3. Lustre vitreous to pearly. Colour white, greyish, yellowish, greenish; also colourless. Transparent to translucent.

Comp. Silicate of lime and magnesia, $Ca. Mg(SiO_3)_2$; usually with from 2 to 3 per cent. of protoxide of iron, sometimes also some oxide of chromium.

Pyr. Like augite.

Loc. Occurs in talc, serpentine, gabbro, and other magnesian rocks. Reported from Dun Mountains, N.Z., and New Caledonia. In association with olivine, diallage, magnetite, spinel, etc., forms the rock *peridotite* at Griqualand, South Africa, the only known matrix of diamond.

57. HYPERSTHENE. Rhombic; angle of proto-prism 93°. Crystals rare, usually in cleavage plates, and massive. Cleavage brachypinacoidal, very perfect; prismatic, distinct; macropinacoidal imperfect and interrupted.

H 5—6. G 3·39. Lustre on cleavage planes pearly, sometimes sub-metallic. Colour dark greyish green, brown to black. Streak grey. Translucent to opaque. Tough.

Comp. Silicate of magnesia and iron, $(Mg. Fe)SiO_3$, usually with some CaO and Al_2O_3, the amount of either being, however, less than 4 per cent.

Pyr. BB fuses above 5; on charcoal to a black magnetic slag. Partially soluble in HCl.

Loc. Forms with labradorite a species of gabbro called *hyperstenite*, and is a common constituent in other kinds of gabbro. Gulgong, Cooma, N.S.W.—Swift's Ck., North Gippsland, Vic.—Parson's Hood Mountain, Heazlewood, Meredith Range, Dundas, Tas.

58. ENSTATITE. Rhombic; angle of proto-prism 92° 30′. Crystals rare, usually cleaved or massive; sometimes fibrous on cleavage planes. Cleavage prismatic perfect, diagonal imperfect.

H 5·5. G 3·1. Lustre vitreous to pearly. Colour greyish, yellowish, or greenish white. Translucent.

Comp. Silicate of magnesia, $MgSiO_3$, usually with some iron and alumina.

Var. *Bronzite.* Colour olive green, greyish green to brown. Lustre adamantine, on cleavage planes frequently metallic.

Comp. $(MgFe)SiO_3$, containing from 6 to 11 per cent. of FeO.

Pyr. F 6. Not affected by HCl.

Loc. In serpentine and peridotite, Mt. Morgan, Q.—Broken Hill, Barrier Range; Tamworth, Nundle, N.S.W.—Magnet Range, Heazlewood, Whyte River, Tas.—Dun Mountains, Nelson, N.Z.—New Caledonia.

59. WOLLASTONITE (*Table Spar*). Monoclinic; tabular prisms. Cleavage basal perfect; usually exhibits a fibrous surface on the cleavage fracture.

H 5. G 2·8. Lustre vitreous to pearly. Colour white, pale yellow to brown. Sub-transparent to translucent. Fracture uneven. Tough.

Comp. Calcium silicate, $CaSiO_3$; sometimes with some mechanically enclosed $CaCO_3$.

Pyr. Fuses at from 4 to 5, colouring the flame brick red. Gelatinizes in HCl. In this solution carbonate of ammonia throws down a white precipitate of $CaCO_3$.

Loc. Occurs in granite, crystalline schists, limestone; sometimes in basalt. Pine River, Q.—Duckmaloi, Sidmouth Valley, N.S.W., with garnet and epidote.—Highwood, south of Hampshire Hills, Tas.—Dun Mountains, Nelson, N.Z.

60. SPODUMENE. Monoclinic; usually large orthopinacoids, often twinned, the plane of composition being that of the orthopinacoid. Also massive. Cleavage orthodiagonal highly perfect; prismatic less perfect.

H 6·5—7. G 3·13—3·19. Lustre vitreous, on cleavage planes pearly. Colour white, greyish, greenish, reddish. Streak white. Translucent to sub-translucent. Fracture uneven.

Comp. Silicate of alumina and lithia, $Li_2Al_2O_4 . 4\ SiO_2 = LiAl(SiO_3)$; the amount of lithia is under 6 per cent. Usually contains some lime and soda.

Pyr. BB whitens, swells, and at 3·5 fuses to a colourless or white glass. Moistened with HCl colours the flame crimson. In the presence of much soda, or in case the amount of lithia is but small, the powdered assay is mixed with fluorspar, potassium bisulphate, and a drop of water to a paste, and fused on platinum wire in the inner blowpipe flame, when the pure lithia coloration will be imparted to the outer flame. With cobalt solution turns blue.

Loc. Usually met with in granite and crystalline schist. Reported from Oura Station, near Wagga, N.S.W. Large crystals, sometimes occupying the space of a cube foot or more, have been found at Norwich, Massachusetts, U.S.A., Sweden, Tyrol, Scotland.

61. BERYL. Hexagonal; usually in six-sided prisms; sometimes a series of stout tabular prisms are piled up so as to form a long, tapering, interrupted column. Isolated crystals are not rarely surmounted by truncated pyramids, and then acquire the form shown in Fig. 116. Always occurs crystallized, or at least broadly columnar.

H 7·5—8. G 2·63—2·76. Lustre vitreous, inclined to resinous. Colour bright green, pale green to white; also pale blue and yellowish. Streak uncoloured. Transparent to translucent. Fracture conchoidal. Brittle.

The bright green transparent variety, called *emerald*, owes its colour to chromic oxide; it is a valuable gem-stone, but distinct from the so-called oriental emerald, which is a green-coloured sapphire. The bluish-green beryl is called *aquamarine*.

Comp. Silicate of alumina and glucina, $Be_3Al_2Si_6O_{18}$.

Pyr. BB fusible above 5 to a sintery glass. In the micro. salt bead leaves a skeleton of silica; emerald so treated imparts to the flux the bright green colour due to chromium. Not acted upon by acids.

Loc. Occurs in clay slate, crystalline schists, kaolinized felsite, or granite porphyry dykes; sometimes in limestone. Frequently also in detrital deposits. In tin-bearing drift at Stanthorpe, Q.; Cope's Ck., Tingha, and Scrubby Gully, N.S.W. With cassiterite in weathered felsite porphyry at Ophir and Emmaville. In the last-mentioned locality emerald mining has been carried on since 1890. Also occurs in tin lodes at Elsmore and Mole Tableland; with arsenopyrite at Shoalhaven River near Bungonia, N.S.W.—Beechworth, Vic.—Barossa, Amianth, Macdonnell Range, S.A.—Mt. Cameron and Flinders Island, Tas. Single crystals of the common beryl, exceeding a foot in length and ten inches in girth, have been found in numerous places in Siberia and North America; one obtained at Grafton, U.S.A., has been estimated to weigh upwards of two tons.

62. OLIVINE (*Chrysolite*). Rhombic; six or eight-sided prisms. Well-terminated crystals exceedingly rare; generally in crystalline or semi-rounded grains. Also massive. Cleavage brachydiagonal imperfect.

H 6—7. G 3·33—3·5. Lustre vitreous. Colour bright green, olive green, greyish green, yellow; sometimes almost colourless. Streak white, or lighter than the colour. Transparent to translucent. Fracture conchoidal. Generally traversed by numerous irregular cracks. Frequently encloses steam or air pores, and cavities filled with liquid.

Comp. Silicate of magnesia and iron, $(Mg, Fe)_2SiO_3$.

Pyr. BB infusible, except the dark-coloured ferruginous variety, which fuses at 4·5 to 5·5 to a black magnetic slag. Gelatinizes with HCl.

Loc. *Precious olivine* or *chrysolite* proper is the brilliant golden-green mineral occasionally used as a gem-stone. Olivine forms an independent rock (olivine rock, dunite); around extinct craters it sometimes constitutes the material of "volcanic bombs," *i. e.* blocks, from three to nine inches in diameter, composed of somewhat loosely compacted grains of olivine; also disseminated in basalt, diabase, etc. In volcanic rocks olivine appears to be one of the earliest separated out of the magma, since it never encloses augite or nephelite, though it occasionally shuts in crystals of magnetite. No mineral is more liable to decomposition and alteration than olivine, the change generally commencing with the oxidation of the iron and proceeding from the outer surface or from the joints towards the centre. The substance then becomes brown and flaky, resembling mica, and is ultimately converted into serpentine, and a mixture of hematite and limonite. In this way olivine rock, and other compounds rich in olivine, have probably most largely contributed to the formation of serpentine.

Occurs at Gatton, Endeavour River, Burnett district, Q., and Inverell, N.S.W., in basalt.—At the Shoalhaven, Hunter, and Louisa Cks. as rolled grains in auriferous drift.—Buninyong, Camperdown, Warrion Hills, Mt. Franklin, Vic., in the form of volcanic bombs. Throughout the volcanic districts of Western Victoria olivine is a constant constituent of the dense basalts, whether these occur in floes or dykes, but is rarely seen in the dolerites. Similarly at Mt. Gambier, Mt. Shank, S.A.—Emu Bay district and Sheffield, Tas.—Arnim Plateau, W.A.—North Island of New Zealand, Auckland, and elsewhere.

GARNET GROUP.

63. GARNET. Isometric; commonly in the rhombic dodecahedron (Fig. 19) and trapezohedron (Fig. 21), or in combinations of these two forms. Octahedral faces rare (Fig. 35). Cleavage dodecahedral indistinct. Also granular and massive.

H 6·5—7·5. G 3·15—4·3. Lustre vitreous to resinous. Colour red, brown, yellow to white, green, black. Streak white. Transparent to translucent. Fracture uneven to conchoidal. Brittle in crystals, tough in massive varieties.

Comp. Silicate of two or more bases, 3 $RO(R_2O_3)3\ SiO_2$, where the protoxide base $RO = CaO$, MgO, or FeO, and the sesquioxide base $R_2O_3 = Al_2O_3$, Fe_2O_3, or Cr_2O_3.

Pyr. Fuse at 3 to 4; the iron-alumina garnet to a magnetic slag, the others to non-magnetic glass. After fusion decomposed by HCl, the silica separating in a gelatinous form. Most deeply-coloured garnets react for iron, some for manganese or chromium.

Var. (*a*) *Almandine*, including *precious garnet* and *common garnet.* Noble garnet is deep red, often with a bluish tinge (pigeon-blood colour), and perfectly transparent. Common garnet is brownish red, translucent to opaque.

Comp. Iron-alumina garnet, $Fe_3(Al_2)Si_3O_{12}$; frequently with some MnO in the place of FeO, and Fe_2O_3 in the place of Al_2O_3.

Loc. Occurs in mica schist, gneiss, granite, felsite porphyry; sometimes in trachyte, often in the midst of the triclinic felspar. Cloncurry, Watsonville, Q.—In mica schist at the Pinnacles near Silverton, N.S.W. With grossularite, quartz, galena, and sphalerite forms an exceedingly fine-grained rock ("garnet sandstone"), which constitutes in places the gangue of the silver lode at Broken Hill. Abercrombie River, Sofala, Yass, Gulgong, Sidmouth Valley, Wallerawang, Tamworth; with epidote at Sunny Corner.

In talc schist at Bathurst, Trunkey. In granite at Hartley, Bingera, Ponds Ck. near Inverell, Uralla, N.S.W.—Mt. Stanley, Ovens district, in dykes of felsite porphyry. Beechworth (almandine) in auriferous drift; similarly at Chiltren, Ararat, Blackwood, Barker's Ck. near Castlemaine, Berwick. Massive with calcite, hornblende, and quartz at Maldon; in the same locality the Silurian schist at the boundary of the granite is in places completely converted into garnet rock. —Mt. Babbage, Bundaleer, Belvidere Range, S.A.—In the Macdonnell Ranges almandine of great brilliancy and depth of colour occurs in rolled grains.—Mt. Heemskirk, Mt. Ramsay, Emu River, Meredith Range, Blue Tier, Tas.—Abounds in crystalline schist in the south-western part of Western Australia.—In gneiss and granulite at Milford Sound and Dusky Sound, Otago; in mica schist at Collingwood, N.Z.

(*b*) *Grossularite;* yellow, brown, white, green.

Comp. Lime-alumina garnet, $Ca_3(Al_2)Si_3O_{12}$, frequently with some Mg, Fe, and Mn. With increased access of iron graduates into common garnet.

Loc. Burnett district, Q., in semi-rounded crystals.—Broken Hill, Mudgee, Nundle, N.S.W.—Beechworth, Vic.—Mt. Claude, Tas.

(*c*) *Pyrope;* dark red, brown, yellow, green.

Comp. Magnesia-alumina garnet, $Mg_3(Al_2)Si_3O_{12}$, part of the alumina often replaced by Fe_2O_3 or Cr_2O_3, and part of the magnesia by MnO. Fuses at 4; with the fluxes usually reacts for iron, chrome, or manganese.

Loc. In serpentine, peridotite, gabbro, etc. New Caledonia.

(*d*) *Andradite;* brownish yellow, brown, dark green to black.

Comp. Lime-iron garnet, $Ca_3(Fe_2)Si_3O_{12}$, usually with some Al_2O_3, MnO, and MgO.

Loc. Wallerawang, N.S.W.—Mt. Claude, Tas.—New Caledonia, in serpentine.

64. VESUVIANITE (*Idocrase*). Tetragonal; commonly in four or eight-sided prisms, having the basal edges replaced by planes of the pyramid. Also granular massive. Cleavage prismatic imperfect, basal indistinct.

H 6·5. G 3·35—3·45. Lustre vitreous to resinous. Colour brown, green, yellow, light blue. Streak white. Transparent to translucent. Fracture uneven.

Comp. Silicate of alumina and lime, $Ca_9Al_4Si_{15}O_{45}$; part of CaO usually replaced by MgO, and part of Al_2O_3 by Fe_2O_3. Usually contains also some protoxide of manganese and basic water.

Pyr. BB swells and fuses at 3 to a greenish or brownish glass, which gelatinizes with HCl.

Loc. Occurs in serpentine, talc, and chlorite schists, crystalline limestone, and other magnesian and calcareous rocks; also in gneiss and in volcanic ejectamenta. Associated with garnet and pyroxene in serpentine at Nundle; with epidote and garnet at Snow Mountains, N.S.W.—In talcose veins at Mt. Ramsay, Tas.—In quartz at Dusky Sound, Otago, N.Z.—With diallage in serpentine, Noumea, New Caledonia.

65. EPIDOTE. Monoclinic; four-sided prisms, generally elongated parallel with the orthodiagonal axis, and surmounted by hemidomes or clinodomes. Also fibrous and granular. Cleavage orthodiagonal perfect, hemidomal distinct.

H 6—7. G 3·4. Lustre vitreous, on cleavage planes sometimes resinous. Colour most commonly yellowish green (*pistacite*); also bright green to olive green and greenish black; sometimes red, yellow, brown, and grey (*zoisite*). Streak white or grey. Translucent. Fracture uneven. Brittle. Double refraction eminent. Dichroic.

Comp. Silicate of lime, alumina, and iron, $Ca_4(Al_2Fe_2)_3Si_6O_{25}$; usually contains some MgO, MnO, and basic water, which accessories do not amount to more than 9 per cent.

Pyr. BB fuses with intumescence to a black or brownish black, often magnetic slag. F 3 to 3·5. In closed tube generally yields water. With fluxes reacts for iron, frequently also for manganese. After fusion gelatinizes in HCl.

Loc. Occurs in crystalline plutonic and metamorphic rocks, granite, syenite, gneiss, amphibolite, etc., usually in association with quartz. Forms with quartz alone an independent rock—"epidote rock." It is but little affected by atmospheric action, and on that account frequently abounds as loose grains in the detritus derived from rocks of the kind just mentioned. Epidote rock is known to occur on New Ireland, to the east of New Guinea.—In hornblende rock at Biggenden, Mt. Shamrock, Ravenswood, Q.—Pistacite and zoisite with axinite at Bingera. In divergent bladed crystals in red jasper, which constitutes the gangue of an auriferous vein at Mt. Moore, Baker's Ck. In schorl rock, Pinnacles near Silverton. In syenite porphyry, Adam's Hill, Lionsville. In Silurian sandstone altered by contact with granite at Sidmouth Valley. In Silurian fossiliferous limestone at Camberra. With quartz at Lewis Ponds, Mt. Tennant, Murrumbidgee, Gulgong, Bathurst, etc., N.S.W.—In a syenite dyke at Talbot; in syenite porphyry at Tarilta, Vic. —In crystalline limestone, Macdonnell Range; with quartz, Yudanamutana, Flinders Range, Amianth Place, Barossa, S.A.—In amphibole rock, Waratah, Magnet Range, Whyte River, Dundas, Port Cygnet, Tas.—In crystalline metamorphic rock with hornblende, garnet, and magnetite at Southern Cross, W.A.—With quartz and chalcopyrite, Dusky Sound, Otago, N.Z.

66. Zircon. Tetragonal; four and eight-sided prisms surmounted by pyramids (Fig. 64). Commonly in rounded grains. Cleavage prismatic imperfect, octahedral indistinct.

H 7·5. G 4·1—4·7. Lustre adamantine. Colour pale shades of brown, yellow, red, bluish green to bright green, grey, colourless or clouded. Streak white. Transparent to translucent. Dichroic. Fracture conchoidal. To the lapidary the clear red zircon is known as *hyacinth*, the colourless, pale yellow, or brown variety as *jargon*.

Comp. Silicate of zirconia, $ZrSiO_4$, frequently with a small amount (up to 2 per cent.) of Fe_2O_3.

Pyr. Infusible; the coloured variety becomes white or colourless. After fusion with soda on platinum wire is decomposed by dilute HCl; the zirconia contained in the solution imparts an orange colour to turmeric paper.

Loc. Occurs in granite, gneiss, granular limestone, and other crystalline rocks, sometimes in such quantities as to form a regular constituent, *e. g.* in zircon-syenite. Common in gold- and tin-drifts throughout Australia, occasionally in perfect or semi-rounded crystals, but mostly in well-worn pebbles and grains. The circumstance that zircon in crystals and pebbles is not rarely met with in elevated, and isolated, basaltic tracts bespeaks for it a volcanic origin, although it has not been hitherto observed in the matrix, except in basalt at Bald Hill near Learmouth, Vic.—Herberton, Burnett, Stanthorpe, Q.—Uralla, Bingera, Mudgee; Cudgegong, Macquarie, Abercrombie, Moama, Shoalhaven, Kiandra, Vegetable Ck., Armidale, Glen Innes, Berrima, Mittagong; in sea-sand at mouth of Clarence River. With diamond, sapphire, and topaz at Duckmaloi Ck. near Oberon, N.S.W.—Omeo, Beechworth, Daylesford, Trentham, Leongatha, Lal Lal, Merino, Dundas, and Black Ranges, Vic.—Echunga, S.A.—Thomas Plains, Ringarooma, Pieman, Flinders Island, Meredith Range, Tas.—Gascoyne, Albury, W.A.

67. Axinite. Triclinic; stout prisms with sharp edges (Fig. 93). Also laminar, granular, and massive. Cleavage brachypinacoidal distinct.

H 6·5—7. G 3·27. Lustre adamantine. Colour clove brown, greyish blue, grey. Streak white. Transparent to translucent. Fracture conchoidal. Brittle. Strongly doubly refracting. Trichroic.

Comp. Silicate of lime, alumina, iron, and manganese, usually with some boric acid, magnesia, and basic water, $H_2(Ca, Fe, Mn, Mg)_6(Al_2B_2)_3Si_8O_{32}$.

Pyr. BB fuses at 2 with intumescence to a dark-green glass, colouring the flame pale green (boric acid). Decomposed by HCl with separation of gelatinous silica.

Loc. Occurs associated with amphibole, garnet, and quartz in crystalline rocks. With epidote at Bingera and Moonbi River, south-east of Tamworth, N.S.W.

MICA GROUP.

The minerals of this group are characterized by their highly perfect basal cleavage, and the toughness and elasticity of the individual cleavage plates. In spite of this property of almost indefinite divisibility, their resistance to the decomposing action of the atmosphere and moisture is exceedingly great. The presence of water in their composition may generally be taken as an indication of incipient decomposition. They frequently result from the transmutation of felspar, tourmaline, etc., and are in their turn liable to become altered to steatite, serpentine, etc.

68. Muscovite (*Potash Mica*). Rhombic; six and eight-sided tables, often aggregated in oblique columns, so as to present a monoclinic aspect. Also in irregular, disseminated scales. Cleavage basal highly perfect.

H 2. G 2·75—3. Lustre pearly. Colour white, silvery white, colourless, grey, greenish, purplish white, yellow, brown. A transparent coating of hydrous ferric oxide sometimes imparts a golden colour to the thin scales. Streak white. Transparent to translucent. Cleavage plates flexible and elastic. Tough. Double refraction strong.

Comp. Silicate of alumina and potash $K_2(Al_2)_3Si_6O_{22}$; almost invariably contains some NaO and H_2O; frequently also CaO, MgO, MnO, Fe_2O_3, and F, which accessories may amount to 25 per cent.

Pyr. BB fuses on the edges to a white or grey enamel, colouring the outer seam of the flame purplish. Often reacts for iron, manganese, or fluorine. Not affected by acids.

Loc. Muscovite enters regularly into the composition of granite, gneiss, mica schist, phyllite, and as an accessory into that of many other crystalline and fragmentary rocks. It is often found in plates measuring several square feet, particularly on the walls of pegmatite dykes. Muldwa, Herberton, Q.—Pinnacles near Silverton, Albury, Kiandra, Bathurst, Elsmore, N.S.W.—Beechworth, Mitta Mitta, Anakies, Balmoral, Vic.—Macdonnell Range, in sheets of considerable size; Alice Springs; Mt. Victoria, black; Outalpa, Hart's Range, Mt. Crawford, S.A.—Blue Tier and St. Helens, Eastern Tasmania, Dundas, Pieman, Waratah, Blythe River, Tas.—Victoria Plains, Champion Bay, Adam Bay, Gascoyne, Bunbury, Kimberley, Pilbarra, W.A.—Stewart Island, Preservation Inlet, Milford Sound, N.Z.

Var. Sericite. Colour greenish to greyish white. Lustre eminently silky (whence the name). Occurs in aggregates of minute scales, generally with quartz in argillaceous rocks, *e.g.* phyllite, sericite schist. It is an hydrated potash mica, perhaps an altered muscovite, containing some 4 per cent. of water. Sericite schist, apparently a transition between clay slate and mica schist, forms partly the country rock in the Australian Broken Hill Mine, Barrier Range. Between Linton and Mt. Bute, Vic.—Extensively developed in the neighbourhood of Penguin and Mt. Zeehan, Tas.

Fuchsite (Chrome Mica), coloured emerald green by chromic oxide, which is present sometimes to the extent of 4 per cent. Dusky Sound, N.Z.

69. LEPIDOLITE (*Lithia Mica*). Rhombic; form and cleavage like muscovite.

H 2·5—4. G 2·84—3. Lustre pearly. Colour silvery white, pale rose red, yellowish, greyish white, purple. Translucent.

Comp. Silicate of alumina potash, and lithia, with some basic water and fluorine, 2 $[(H_2KLi)O, Al_2O_3. 2 SiO_2] + Si_2O_3F_2$. May be considered a muscovite in which part of the potash is replaced by lithia. The percentage of lithia is usually under 5, that of fluorine sometimes exceeds 10. Iron and manganese are rarely absent.

Pyr. BB fuses with intumescence to a white enamel, or, in the presence of much iron, to a magnetic slag. F 2. Flame coloration crimson. In closed tube yields water. Slightly affected by acids. The fused mineral gelatinizes with HCl.

Loc. Occurs in greisen and tin granite usually in association with other fluorides, *e.g.* topaz, schorl, apatite, fluorspar. Waukaroo, Barrier Range; Jinjellic, Upper Murray; Mole Tableland, New England, N.S.W.—Mt. Wills, Vic.—Mt. Ramsay, Blue Tier, Port Cygnet, Tas.

70. BIOTITE (*Magnesia Mica*). Hexagonal; thin six-sided tables, presenting a monoclinic aspect. Cleavage basal highly perfect.

H 2·5—3. G 2·7—3·1. Lustre splendent, often submetallic. Colour dark green, dark brown to black. Streak white or grey. Transparent to nearly opaque.

Comp. Silicate of alumina, magnesia, potash, and iron; usually with some water, frequently also soda, fluorine, and manganese; $K_2Al_6(FeMg)_{12}Si_6O_{34}$.

Pyr. BB fuses on thin edges at from 5·5 to 6. In closed tube gives a little water. Decomposed by H_2SO_4 with separation of flaky silica.

Loc. Biotite, though less abundant, has a wider geological range than muscovite. While the latter is confined to the older acidic rocks and their derivatives, biotite takes part in the composition of both acidic and basic rocks of every age, *e.g.* granite, syenite, minette, diorite, porphyrite, rhyolite, basalt, peridotite, etc. Ravenswood, Q., in syenite. Barrier Range, with chalcopyrite in minette.—In granite throughout Victoria; Heathcote, in granitite boulders of Permian conglomerate; Ballark near Steiglitz, in mica syenite; Eureka

Reef, Castlemaine, in a dyke of basalt; Dandenong Range in porphyrite; Walhalla and Woods Point in diorite.—Bremer Range, Teetulpa, Mt. Babbage, S.A.—Flinders Island, Blue Tier, Heemskirk, Ramsay, Whyte River, Tas.—Gascoyne, Murchison, Kimberley, W.A.

Var. *Rubellane*, a red-brown variety of biotite, often seen in decomposed basalt and volcanic tuff, resulting from the alteration of olivine, *e. g.* Buninyong, Learmouth, Mt. Franklin, Footscray, Vic.

71. LEPIDOMELANE (*Iron-Potash Mica*). Hexagonal; form and cleavage like biotite.

H 3. G 3. Colour black to greenish black. Streak greenish grey. Lustre adamantine. Translucent to opaque. Plates less elastic than those of biotite.

Comp. Silicate of alumina, potash, and iron frequently with MgO, CaO, MnO, Na_2O, and H_2O; $H_4K_2(Al_2Fe_2)_3Si_6O_{24}$.

Pyr. BB fuses at 2 to a black magnetic slag. Usually gives water in the closed tube. Decomposed by HCl with separation of powdery silica.

Loc. Lepidomelane is much less common than the other species of mica; it occurs usually in rocks affected by contact metamorphism. Pinnacles near Silverton, N.S.W., with galena in garnet rock.—Eldorado near Beechworth, Vic., on quartz in pegmatite.—Mt. Heemskirk, Tas., in amphibolite.

LEUCITE GROUP.

72. LEUCITE. Isometric (? Tetragonal); in crystals resembling the deltohedron (Fig. 21); surfaces of crystals dull. Also in scattered grains.

H 6. G 2·5. Lustre vitreous. Colour and streak white or greyish. Translucent to opaque. Fracture conchoidal. Brittle.

Comp. Silicate of alumina and potash, $K_2(Al_2)Si_4O_{12}$; usually with some soda.

Pyr. BB infusible. Heated with cobalt solution turns blue. Decomposed by HCl with separation of powdery silica.

Loc. Leucite is essentially of volcanic origin, and in certain defined localities forms a regular constituent of basalt. While it has never been observed in the basalts of Northern and Western Europe (Great Britain, Scandinavia, France), it is ever present in the tertiary and quaternary lavas which lie within a belt extending from the Eifel on the Rhine to Bohemia. Similarly the volcanic rocks of Southern Italy are as a rule leucitic. Some of the Vesuvian lavas (leucitophyre) are remarkable for the size and perfect development of the crystals of leucite they contain. These crystals often enclose crystallized augite, olivine, and apatite. Leucite basalt occurs in outliers capping pliocene conglomerate at El Capitain, thirty miles south of Bourke, N.S.W., and at Byrock, some ten miles further south. It is quite possible that the presence of this mineral may yet be proved in many Australian lavas that have not hitherto been subjected to microscopic analysis. Under the microscope the crystal sections are usually eight-sided, and distinctly marked by twin striations in two or four different directions. The crystals are frequently rounded as if by a second fusion. On decomposition leucite is liable to be altered to nephelite, kaolin, analcite, and sanidine; the last-mentioned mineral is known to occur pseudomorphous after leucite.

73. NEPHELITE. Hexagonal; six or twelve-sided prisms, with the upper edges usually replaced. Cleavage prismatic perfect, basal imperfect.

H 6. G 2·5—2·65. Lustre vitreous to resinous. Colour white, yellowish white, colourless. Transparent to translucent. Fracture uneven.

Comp. Silicate of alumina, soda and potash, usually also lime, and frequently with traces of iron and water; $(Na, K)_2(Al)_2Si_2O_8$.

Pyr. BB fuses at 3·5 to a transparent glass. Gelatinizes with HCl; in the remaining solution NH_3 produces a precipitate of hydrate of alumina.

Loc. Nephelite occurs in recent and tertiary volcanic rocks, such as basalt, dolerite, phonolite, in disseminated, minute, glassy, colourless crystals, which on decomposition frequently give rise to the formation of analcite, natrolite, and other soda zeolites. In the lavas of the Canary, Cape Verd, and Sandwich Islands, as also of the Eifel, nephelite occupies the place of a regular constituent (nephelinite). In the older (miocene) basalt of Phillip Island and Western Port, Vic., it occurs as an accessory.—Dowagarang near Wellington, Pinnacle near Forbes, N.S.W.

Var. *Elaeolite;* has the same composition as nephelite, but differs as to physical properties and habitat. Colour dark green, grey brown, or red. Crystals large, frequently occurs massive. Restricted to ancient eruptive and metamorphic rocks, *e.g.* syenite, gneiss. Arkansas, U.S.A., Scandinavia, Transylvania, Ural, Siberia.

FELSPAR GROUP.

The minerals of this group are, according to morphological character, separable into two sections—the monoclinic (orthoclastic) and the triclinic (plagioclastic) felspars. In the former the principal cleavage planes are parallel to the base and clinodiagonal, *i. e.* normal to each other (orthoclastic); in the second the cleavages are parallel to the base and brachydiagonal, *i. e.* intersect each other under an oblique angle (plagioclastic). The cleavage angles of the several species are as follows—

Orthoclase	90°
Albite	86° 24′
Oligoclase	86° 18′
Andesite	86° 14′
Labradorite	86° 04′
Anorthite	85° 50′

Macled prisms are common forms among all the species. In triclinic felspars the polysynthetic twinning displays itself by a fine striation on the basal cleavage surfaces, and when viewed under the polariscope by a strong contrast of colours in the different lamellæ—characters which serve to distinguish them from the orthoclases.

The felspars are essentially compounds of silicate of alumina and silicates of potash, soda, and lime. It is customary to speak of certain members of this group as soda felspar, potash felspar, etc., but it must be borne in mind that both potash and soda are present with rare exceptions in every felspar. The triclinic felspars are the more basic, lime (or lime and alkalies) entering most largely into their composition. The monoclinic felspars, on the other hand, always contain an excess of alkalies. Neglecting variable and non-essential constituents, the following table gives the percentage composition of the principal felspars—

	SiO_2.	Al_2O_3.	K_2O.	Na_2O.	CaO.
Orthoclase . . .	64·7	18·4	16·9	—	—
Albite	68·7	19·5	—	11·8	—
Oligoclase. . . .	63—60	23—25	—	9—8	4—7
Andesite	58—56	27—28	—	7—6	8—10
Labradorite . . .	54—49	30—33	—	5—3	12—15
Anorthite	43·2	36·7	—	—	20·1

Albite and anorthite stand at opposite extremes of the triclinic series, are practically isomorphous, and have each a fixed and constant composition. The other plagioclastic felspars may accordingly be regarded as isomorphous mixtures of molecules of these two compounds, thus—

	Ratio of albite (Ab) to anorthite (An).
Albite	Ab.
Oligoclase . .	Ab_6An_1 to Ab_3An_1.
Andesite . . .	Ab_3An_1 to Ab_1An_1.
Labradorite . .	Ab_1An_1 to Ab_1An_3.
Anorthite. . .	An.

In their normal condition the felspars are anhydrous compounds, but when undergoing decomposition they readily take up water. Generally speaking, the plagioclastic felspars, with the exception of albite, yield more readily to the influence of weathering than the orthoclases.

74. ORTHOCLASE (*Potash Felspar*). Monoclinic; usually six-sided prisms terminated by planes of the clinodome or hemidome (Fig. 91). Macles common, more particularly the "Carlsbad type" illustrated by Figs. 140 to 144, and the "Baveno type" shown in Figs. 145 and 146. Also laminar, granular, and massive. Cleavage basal perfect, clinodiagonal less perfect, orthodiagonal and prismatic indistinct.

H 6. G 2·5—2·6. Lustre vitreous to pearly, after lengthy exposure becomes externally dull. Colour white, yellowish, greenish, flesh red, brown red. Streak white. Transparent to translucent. Fracture sub-conchoidal.

Comp. Silicate of alumina and potash, $K_2(Al_2)Si_6O_{16} = KAlSi_3O_8$; usually with soda, lime, and peroxide of iron; frequently also contains magnesia and baryta. The aggregate amount of these accessories rarely exceeds 6 per cent.

Pyr. BB fuses quietly at 5. Heated in the lower fringe of the oxidizing flame imparts to it a violet colour. (Heating at the point of the flame is less satisfactory.) Insoluble in acids.

Loc. Orthoclase is an invariable constituent of many plutonic and metamorphic rocks, such as granite, syenite, felsite porphyry, gneiss, etc., in which it occurs either in crystalline, cleavable masses, or in porphyritic crystals. With quartz it forms the compact rock *felsite*, in which the felspar assumes variously a cryptocrystalline, dense, or glassy structure. From the circumstance that orthoclase has been rarely, if ever, observed in volcanic rocks it is inferred to be of hydro-plutonic origin. In some instances, *e.g.* at Learmouth, and at the Moorabool Falls near Lal Lal, Vic., the presence of orthoclase (and of quartz as well) in dolerite is probably due to mechanical causes, fragments of granite having probably become detached from the wall rock during the ascent of the lava. It is to be noted, however, that orthoclase crystals have been artificially produced in the slag of smelting furnaces. When orthoclase is attacked by carbonated water, decomposition sets in, causing a loss of lustre, a diminution of the bases—alkalies, magnesia, lime (when present)—as well as of silica, and absorption of water. Oxidation converts the carbonate of iron (if present) into ferric hydrate, which gives the mass a reddish or brownish tinge. Sometimes this is re-converted into carbonate and wholly removed in solution, leaving the mineral white. As decomposition progresses the whole of the alkaline bases and two-thirds of the silica may be removed, and so lead to the formation of kaolin. The process of kaolinization may be explained thus—

$$\begin{array}{lcl}
\text{Orthoclase} & = & K_2O + Al_2O_3 + 6\ SiO_2 \\
 & & -\ K_2O \qquad\qquad -\ 4\ SiO_2 + 2\ H_2O \\
\hline
\text{Kaolin} & = & Al_2O_3 + 2\ SiO_2 + 2\ H_2O
\end{array}$$

The geographical distribution of orthoclase is so extensive that reference is made here only to localities in which the mineral occurs abundantly and in fairly developed crystals. Star River, Herberton, Stanthorpe, Ballandean, Q.—Pinnacles, Silverton, Broken Hill; Waukeroo, Barrier Range, in stanniferous pegmatite; Tenterfield, Glen Innes, Armidale, Bathurst, Pambula, N.S.W.—Lal Lal, Manibadar near Linton; Mt. Singapore, Wilson's Promontory; Bradford Lead and Nuggetty Reef, Maldon; Wannon Falls near Coleraine, in felsite porphyry; Black Range near Stawell, Vic.—Angaston, Teetulpa, Mt. Babbage, Crystal Brook, Wells Ck., S.A.—Blue Tier, Ben Lomond, Flinders Island; Port Cygnet in rhomb porphyry; Mt. Heemskirk, Tas.—Albany, Northam, Murchison, Dundas, Pilbarra, W.A.—South-western Otago, N.Z.

Var. Adularia. Laminar, transparent, with pearly or opaline lustre. Mt. Lindsay, Montague Island, N.S.W.—Reid's Ck. near Beechworth. Head of Arthur River, Upper Huskisson River, Tas.—In the neighbourhood of Albany, W.A.

Amazonstone. Bright green, coloured by salts of copper. Pinnacles, Barrier Range.

Erythrite. Translucent, flesh red to rose red. Moonta, S.A.

Murchisonite. Pale red with bright yellow or golden reflections, due to interspersed albite. Reported from Reid's Ck. near Beechworth.

Microline. Massive, in cleavable prisms; rich in soda, the amount of which (up to 7 per cent.) sometimes equals that of potash, thus placing it intermediate between orthoclase and albite. In obedience to the law of chemical and morphological interaction the cleavage angle is no longer 90°, but diminishes to from 89° 52′ to 89° 46′; on strict crystallographical principles, therefore, microline should be classed among the triclinic felspars. Mundi, Pinnacles, Silverton, Barrier Range. Suliman Pasha Mine, Ballarat East.

75. SANIDINE (*Glassy Felspar*). Monoclinic; in thin tabular prisms. Cleavage like orthoclase.

H 6·5. G 2·6. Lustre highly vitreous. Colour white, greyish white, sometimes colourless. Streak white. Transparent to sub-translucent. Fracture conchoidal.

Comp. Silicate of alumina, potash, and soda, $(K_2Na_2)(Al_2)Si_6O_{16}$, usually with some iron and lime.

Pyr. Like orthoclase, but more easily fusible.

Loc. From similarity of composition sanidine might properly be placed next to microline as a variety of orthoclase, were it not that its distinct habitus entitles it to rank as a separate species. Sanidine is exclusively a volcanic product, its occurrence being confined to certain of the younger volcanic rocks, liparite (quartz rhyolite), trachyte, phonolite, of which it is indeed the principal constituent. Thus in trachyte at Port Curtis, Q.—Urombong, County of Gowen; Benada Creek, Naas, Lanyan, Mt. Wingen, N.S.W.—In phonolite dykes, Northern Territory of S.A.—In trachytic and rhyolitic lavas at Mt. Egmont, Rotomahana, and elsewhere on both islands of New Zealand.

76. Albite (*Soda Felspar*). Triclinic; normally six-sided prisms, terminating in brachydomes (Fig. 94), but simple forms are rare; usually in macles having the plane of composition parallel to the brachypinacoid, in the manner shown in Figs. 149 and 150 (*albite type* of twinning). Polysynthetic twinning common, recognizable by a fine striation on basal surfaces. Also laminated, massive, and compact. Cleavage parallel to the base and brachypinacoid, both perfect.

H 6. G 2·6. Lustre vitreous. Colour and streak white. On basal cleavage surfaces sometimes bluish with a pearly lustre. Transparent to translucent. Fracture uneven. Brittle.

Comp. Silicate of alumina and soda, $Na_2(Al_2)Si_6O_{16}$; usually with some potash, lime, and magnesia; occasionally also protoxide of iron.

Pyr. BB fusible at 4 to a transparent glass. Yellow flame coloration. Insoluble in acids.

Loc. Albite takes a prominent part in the constitution of some kinds of granite gneiss, felsite porphyry, and diorite. Also occurs in metamorphic sandstone and in metalliferous veins. Like orthoclase it is liable to be altered into kaolin as explained above. Gympie, Q.—Bingera, Gulgong, Mt. Dixon, head of Yarralumla River, Umberumberka, N.S.W. —In schorl granite, Wilson's Promontory. In auriferous quartz veins and segregations traversing Silurian slate and sandstone, Ballarat East; Albion Reef, Steiglitz; Blacksmith's Reef, Vaughan; Eaglehawk Reef, Bendigo, Vic.—Olabidnie Ck., S.A.—Mt. Zeehan, Tas.—Southern Cross, W.A.

77. Oligoclase. Triclinic; form and structure like albite, with such differences as were pointed out in the general observations at the head of this section.

H 6·5. G 2·6–2·7. Lustre vitreous, pearly to resinous. Colour usually white, inclined to greyish, greenish, or reddish tints. Occasionally faintly opalescent. Transparent to translucent. Fracture uneven. Brittle.

Comp. Silicate of alumina, soda, and lime, $Na_2(Al_2)Si_6O_{16} + Ca(Al_2)S_2O_8$; usually with some potash and magnesia.

Pyr. Like albite, but fuses somewhat more readily.

Loc. Oligoclase, although not occurring abundantly in any one locality, has a wider geological range than most other felspars, affecting alike the most ancient plutonic and the youngest volcanic rocks. Charters Towers, Q., in granite; Herberton in syenite; Carrawal in serpentine. Pinnacles and Silverton in granitite; elsewhere in the Barrier Range in amphibolite. In basalt at Collingwood; Lachlan, Fish River, N.S.W.—A subordinate but frequent constituent in many Victorian granites, *e.g.* Mt. Alexander, Gong Gong near Ballarat, Station Peak near Geelong. In lava and tufa around the extinct craters of Anakies, Buninyong; Moorookyle, Smeaton Hill, and Spring Hill near Creswick; Franklin, Camperdown, Mt. Eccles, and others in Western Victoria.

Var. Moonstone. White opalescent; a property probably due to interlaminated flakes of orthoclase or albite. A similar opalescence has been observed in some varieties of orthoclase, to which the name "moonstone" has then also been applied.

Sunstone (*Aventurine felspar*). Light grey, often with a tinge of red. Encloses minute plates of specular iron, the reflections from which impart to it a lustre somewhat like that of fire opal.

78. ANDESINE. Triclinic, usually in cleavage prisms, as a rule macled. Also granular or massive. Cleavage like albite, but less perfect.

H 5—6. G 2·61—2·74. Colour white, grey, reddish or yellowish white. Lustre vitreous to pearly.

Comp. Silicate of alumina, soda, and lime; $Na_2(Al_2)Si_2O_{16} + Ca(Al_2)Si_2O_8$; usually with magnesia, iron, and potash.

Pyr. BB fuses at 5·5 to a clear glass. Partly dissolved by HCl.

Loc. Andesine in combination with amphibole and augite forms particular kinds of volcanic rocks, which from being extensively developed in the Andes, South America, have been called ***andesites***. As the name (correctly spelled according to mineralogical rule) is in current use among petrographers, it cannot now be adopted for the mineral species. On the grounds that andesite stands in regard to silica ratio intermediate between dolerite and trachyte, it has been thought proper to provisionally assign certain Australian eruptive rocks to this position, *e.g.* the plagioclase-augite rocks occurring in dykes at Mt. Morgan and Mt. Leyshon, Q.; Tokatea, Coromandel, N.Z.; as well as some of the lavas around Tarawera, N.Z. Further microscopic and chemical research is needed, however, before an absolute determination can be made in the instances quoted. The question, moreover, involves not alone scientific interests, but is fraught with considerable economic importance in view of the circumstance that some of the richest deposits of gold and silver ores have been met with in association with andesitic rocks, *e.g.* Comstock, Nevada; Schemnitz, Hungary; Transylvania, etc.

79. LABRADORITE. Triclinic; form and structure like albite. Also in cleavable masses, granular, and compact.

H 6. G 2·7—2·76. Lustre vitreous to pearly. Colour white, grey, greenish, brownish; on smooth surfaces displays chatoyant colours, especially green, blue, and brown, sometimes metallic red. In some colourless varieties this play of colours is absent. Streak white. Translucent, sometimes limpid. Brittle, but less so than oligoclase.

Comp. Silicate of alumina, soda, and lime, $Na_2(Al_2)Si_6O_{16} + Ca(Al_2)Si_2O_8$; usually with some potash and peroxide of iron.

Pyr. BB fuses at 3 to an uncoloured glass. Partially soluble in HCl.

Loc. Labradorite takes part in the composition of numerous amphibole and pyroxene rocks, *e.g.* diabase, diorite, basalt, but occurs rarely in rocks containing free silica (quartz). Mt. Eurie near Cloncurry, Q.—Forms the principal constituent of the pliocene and post-tertiary lavas of Victoria; in the porphyritic dolerite of Sebastopol near Ballarat, Adekate Creek near Creswick, Loddon near Vaughan, Malmsbury, etc., the narrow, lath-shaped crystals are sufficiently large to be recognized by the unaided eye. In gabbro at Barrabool Hills near Geelong; Mt. Wellington, Gippsland; Waratah Bay, west of Wilson's Promontory.

80. ANORTHITE. Triclinic; prisms stout or tabular. Also laminated, and massive. Twin forms and cleavage like albite.

H 6—7. G 2·7—2·75. Lustre vitreous to resinous, on cleavage planes pearly. Colour white, greyish, and reddish. Streak white. Transparent to translucent. Fracture conchoidal. Brittle.

Comp. Silicate of alumina and lime, $Ca(Al_2)Si_2O_8$; usually with some soda, potash, magnesia, and iron, which ingredients amount sometimes to as much as 12 per cent. of the mass.

Pyr. BB fuses at 5 to a colourless glass. Gelatinizes with HCl.

Loc. Anorthite affects two distinct habits of occurrence: the alkaline varieties are met with chiefly in the older eruptive rocks, *e.g.* granite, gabbro, diorite; the normal lime anorthite being confined to recent volcanic rocks. The finest crystals have been obtained in Vesuvian tufa. In most cases the presence of anorthite in a massive rock can only be determined by microscopic examination.

81. AMORPHOUS FELSPAR. The mineral substances to be considered under this head are essentially mixtures of one or more kinds of felspar with free silica and oxide of iron; the amount of silica varying from 60 to 80 per cent. They are therefore not genuine minerals, but fused

rocks, and being mostly of modern volcanic origin are usually described by petrographers under the term *volcanic glass.*

(*a*) *Obsidian.* H 7. G 2·3—2·8. Lustre glassy, colour black, greyish, greenish, brownish; not rarely exhibits a play of colours due to internal rifts or foreign enclosures. Transparent to translucent. To the naked eye it presents the character of a limpid homogeneous glass; under the microscope thin sections appear clouded, banded, or streaky, as if portions of the fused substance had been imperfectly dissolved in the glass, and is seen to contain numerous minute bodies (crystallites, spherulites, trichites), often with their longer axis arranged along one and the same direction, indicating the trend of the flowing liquid mass (fluxion structure). Fracture eminently conchoidal.

Comp. SiO_2 68—80, Al_2O_3 5—16, also K_2O, Na_2O, CaO, and Fe_2O_3, but no water or only traces.

Pyr. BB fusible at from 3 to 4·5.

Loc. Occurs in ejected blocks, more rarely in subordinate sheet-like masses, generally associated with the more acidic volcanic rocks. New Britain, Sudest, and other volcanic islands of the Eastern Archipelago.—Ballarat, Koroit, Vic.—Mayor Island, Auckland, N.Z.—Mt. Gambier, S.A. Embedded in the surface soil and drifts on, and adjacent to, lava floes there occur in many parts of Victoria and Tasmania globular, hemispherical, button-shaped, or disk-like pieces of obsidian, from half-an-inch to two inches in diameter, which no doubt share the origin of ordinary lapilli and other volcanic ejecta. Similar obsidian bombs have been discovered here and there on the plains of Northern Victoria, New South Wales, and even in Central and Northern Australia, in situations wholly unconnected with any outcropping volcanic rock. The suggestion made that the aborigines may have used these attractive-looking stones as articles of barter affords the only feasible explanation of their wide distribution over the continent. At the mouths of craters obsidian is sometimes by the action of currents of vapour or air torn into thin asbestus-like threads (*Pelè's Hair* on Sandwich Islands). The black shining substance often encountered at the base of the lowest lava sheet at Sebastopol, Ballarat, is not obsidian, though so called by the local miner, but tachylite, a glassy variety of basalt.

(*b*) *Pumice;* is substantially an obsidian with a highly vesicular, frothy, sometimes fibrous texture, and exhibiting under the microscope well-marked fluxion structure. Lustre vitreous, pearly, silky. White, grey, yellowish. H 4. G 2.

Volcanic Islands of Eastern Archipelago.

(*c*) *Pitchstone.* Leek green, black, brown, reddish, or yellowish. Lustre greasy or pitch-like. Fracture conchoidal. Two varieties are distinguished, viz. *Felsite Pitchstone,* a vitreous kind of felsite, and *Trachytic Pitchstone,* apparently a glassy mixture of sanidine, plagioclase, and quartz, containing steam pores, vesicles filled with water, and microlites of sanidine and augite, undoubtedly a volcanic product.

H 5·5 to 6. G 2·2.

Comp. SiO_2 76, Al_2O_3 11—15, H_2O 4—8; also Na_2O, K_2O, Fe_2O_2, etc.

Pyr. F 3—4. Yields water in close tube.

Loc. Much of what is called obsidian is really pitchstone. Ballarat, Camperdown, Mt. Gambier; Port Stephens, N.S.W. —Sheffield, Tas.

(*d*) *Pearlstone.* Colourless, pearl grey, reddish, brown. Translucent with greasy lustre. Structure spheroidal ("*perlitic*"), probably an incipient stage of concretionary formation. Under the microscope perlitic structure reveals itself as a series of faint concentric lines spaced somewhat far apart, and forming segments rather than complete circles.

H 6. G 2·3.

Comp. SiO_2 72—77, Al_2O_3 12, H_2O 3—4; also Na_2O, K_2O, Fe_2O_3.

Loc. Occurs in volcanic districts under conditions similar to obsidian and pitchstone.

SCAPOLITE GROUP.

82. **WERNERITE** (*Scapolite*). Tetragonal; eight-sided prisms with pyramidal terminations. Perfect crystals are rare; commonly granular or massive. Sometimes inclined to develop columnar and even fibrous structure. Cleavage diagonal ($\infty P \infty$) distinct, prismatic (∞P) less so.

H 5—6. G 2·63—2·8. Lustre vitreous to resinous. Colour white, or light tints of grey, blue, green, or red. Streak white. Transparent to translucent. Fracture uneven. Brittle.

Comp. Silicate of alumina, lime, and soda, $(Na_2Ca)(Al_2)Si_2O_8$; with variable proportions of magnesia, potash, peroxide of iron; usually contains water.

Pyr. BB fuses at 2·5 with intumescence to a white vesicular glass. Decomposed by HCl, leaving a residue of powdery silica.

Loc. Wernerite is in most, if not all, cases a product of contact metamorphism, occurring chiefly in crystalline schists and limestone bordering on granite and other eruptive rocks. It is liable to be altered to mica, epidote, steatite, and kaolin, all which minerals have been observed pseudomorphous after wernerite. Lady Annie Mine, Cawarral, Q., coloured green by chromic oxide, with quartz. —Prospect Reservoir near Sydney, in decomposed calciferous greenstone.—Dun Mountains, Nelson, N.Z.

83. **TOURMALINE.** Hexagonal; six, nine, or twelve-sided prisms, surmounted by planes of the rhombohedron (Fig. 121), usually only on one side (hemimorphous). Frequently hemihedral. Prisms vertically deeply striated. Columnar, fibrous, often divergent; also massive. Cleavage rhombohedral indistinct.

H 7. G 2·94—3·3. Lustre vitreous. Colour most commonly black, brownish or bluish black; also blue, purple, red, green; sometimes white, very rarely colourless. Streak white.

Eminently dichroic, exhibiting when viewed in the direction of the principal axis a yellowish-brown, purplish-brown, or violet colour, while the corresponding colours in a transverse direction are respectively green, greenish blue, or pale blue. When the principal axis of a tourmaline crystal is placed under right angles to the brachydiagonal of the polarizer, the section appears black or nearly opaque, while in the reverse position it is green or brown. Transparent to sub-translucent; less transparent in basal sections, *i. e.* in the direction of the chief axis, than in that of the lateral axes. Double refraction strong (*vide* par. 98 (2), p. 95). Fracture uneven. Brittle. Pyro-electric.

Comp. Silicate of alumina, magnesia, lime, potash, soda, with some boric acid, $(K_2Na_2MgCa)_3(Al_2)(B_2)_2Si_9O_{45}$; usually contains some oxide of iron and manganese, sometimes also phosphoric acid, fluorine, lithia, and water. The proportions in which these constituents are present vary considerably in different varieties, thus MgO 1—15, Fe_2O_3 1—13, B 4—10.

Pyr. F 3 to 5; varieties rich in magnesia fuse easily; those with much iron fuse at 4 to 5; others which contain no magnesia or iron are infusible. Fused with potassium bisulphate and fluorspar give the green flame coloration of boron (*vide* par. 124). Most varieties after being fused gelatinize in HCl or H_2SO_4.

Var. *Schorl;* the common black variety.

Rubellite; rose to violet red.

Indicolite; pale blue to bluish black.

Loc. Occurs with quartz in granitic and metamorphic rocks, but has never been observed in volcanic rocks. Frequently associated with tin ore. In some kinds of granite it forms a regular constituent (schorl granite; luxullianite). Constitutes, usually in combination with quartz, a crystalline granular or massive rock (schorl rock). Takes a prominent part in the composition of *schorl schist*, a compound of fibrous tourmaline, quartz, mica, and argillaceous matter. Normanby Range near Bowen; Stuart Valley and St. John's Ck., Burnett district; Mt. Perry; with tin ore at Tinaroo; with wolfram and tin ore in felsite near Cooktown, Q.—Albury, Jinjellic, Sunny Corner, Wallangra, Attunga near Tamworth, Cope's Ck., Bindemeer, Nundle, Wombat near Young, Capertree, Oban, Babola, Cooma, N.S.W.—Schorl granite at Mt. Singapore, Wilson's Promontory; Eldorado near Beechworth; Maldon, Pyalong, Mt. Korong, Berwick. Schorl schist to the north of Manibadar near Linton; Carapooee near St. Arnaud. In aplite at Rowsley. Green tourmaline at Beechworth and Baw Baw Range. Acicular crystals in rock crystal at Superb Reef, west of Linton; Point Ulrich near Maldon. Divergent columnar, Reedy Ck. near Kilmore, Vic.—Green tourmaline at Boolcamatta; Macdonnell Range. Schorl at Angaston, Mt. Coltago, Wackaringa, Moonta, Barossa, Encounter Bay, Flinders Heights, S.A.—In stanniferous granite, Blue Tier, Ben Lomond, Pieman River, Meredith Range, Mt. Ramsay. Abundant in bluish-green radiating tufts in the tin- and topaz-bearing felsite porphyry of Mt. Bischoff, Tas.—Albury, York, Gascoyne, Dundas, head of Murchison River, W.A.—Parapara, Nelson, N.Z.

Tourmaline has been observed pseudomorphous after orthoclase. On decomposition yields mica, talc, and chlorite.

84. ANDALUSITE. Rhombic; primary form a four-sided prism whose obtuse angle is 91° 30′, both vertical and lateral edges usually replaced by narrow planes. Frequently columnar, parallel, and divergent; also granular and massive. Cleavage prismatic perfect, diagonal indistinct.

H 7·5. G 3·1—3·3. Lustre vitreous. Some impure varieties have H 3—4, G 3, and are lustreless. Colour white, pink, amethystine, brown, grey, or green. Streak white. Transparent to opaque. Fracture uneven. Strongly doubly refracting.

Comp. Silicate of alumina, Al_2SiO_5, usually with some

K_2O, CaO, MgO, and Fe_2O_3, which accessory ingredients sometimes amount to as much as 10 per cent.

Pyr. Infusible. Heated with cobalt solution becomes blue. In the micro. salt bead the bases are dissolved, leaving a skeleton of silica. Insoluble in acids.

Var. Andalusite proper excels in hardness, density, and lustre. Occurs in mica schist, gneiss, and other crystalline schists.

Chiastolite is softer, and generally contains much ferric oxide. Occurs in long slender prisms in phyllite, clay slate, and other argillaceous rocks of a less pronounced metamorphic character. The axis and angles are frequently of different colours from the rest of the crystal, a transverse section of which represents in consequence a coloured cross or tesselar design. As may be inferred, this peculiarity arises not so much from structural differences as from the fact that the impure matter (Fe_2O_3, MgO, CaO, etc.) contained in the mass has collected in particular parts of the crystal. "Spotted schist," an altered form of clay slate, commonly met with at the boundary of granite, owes its character to sporadic crystallization of molecules, which are perhaps in part those of chiastolite.

Loc. Dry River district near Herberton, Q.—In water-worn blocks in Buna Ck. near Tumbarumba, N.S.W. Chiastolite slate occurs to the east of Bungonia, N.S.W.; in country between Linton and Mt. Bute; Kalymna, south-west of Mt. Ararat; Mt. William near Lancefield; Inglewood, Vic.—Blue Tier, and Mt. Zeehan, Tas.

85. TOPAZ. Rhombic; polygonal prisms terminating, usually on one side only, in truncated pyramids. Prismal faces as a rule vertically striated. Also columnar and granular. Cleavage basal very perfect.

H 8. G 3·4—3·65. Lustre vitreous. Colour pale brownish yellow, or reddish yellow; greyish, greenish, bluish, or reddish white; sometimes white or colourless. Streak white. Transparent to translucent. Strong double refraction. Fracture uneven. Brittle. Pyro-electric.

Comp. Silicate of alumina with silicic fluoride, $5\,(Al_2)SiO_5 + (Al_2)SiF_{10}$. The amount of fluorine varies from 15 to 18 per cent. Often encloses microscopic scales of hematite or limonite.

Pyr. Infusible, but often changes colour: white or pale varieties to yellow, yellow varieties to red, after strong heating. Fused with micro. salt in the open tube reacts for fluorine. Ignited with cobalt solution assumes a blue colour. Not affected by acids.

Loc. Found crystallized in nests and veins in pegmatite, gneiss, and crystalline schists; granular in felsite porphyry; in the form of loose crystals and pebbles, more or less waterworn, in recent auriferous and stanniferous drifts, and generally in detritus derived from the rocks mentioned. In stream tin deposits at Stanthorpe, Star River, Tinaroo, Herberton, Q., and New England.—At Gundagai, Gulgong, Glen Ck., Scrubby Gully, Mole Tableland, Inverell, Oban, Uralla, Bingera, Bathurst, Shoalhaven, Abercrombie River, N.S.W.—In auriferous alluvial at Omeo, Beechworth, Leongatha, Bendigo, Castlemaine, Maldon, Blackwood, Lal Lal, Talbot, Ararat, Stawell, Balmoral, Merino, Vic.—Flinders Island, Mt. Cameron, Blue Tier, Ringarooma, Tas. The white porphyry composing the summit of Mt. Bischoff contains in a felsitic base crystals of quartz and an abundance of fine-grained amorphous topaz, with here and there a cavity lined with groups of radiating acicular crystals of topaz. Pseudomorphs of topaz after quartz are also not uncommon. The rock is rich in tourmaline and cassiterite.

86. Staurolite. Rhombic; six-sided prisms, usually in penetration twins, the individuals of which cross either under right angles or obliquely (Fig. 138). Crystal surfaces usually rough. Not known in an uncrystallized condition. Cleavage brachydiagonal distinct.

H 7—7·5. G 3·4—3·8. Lustre vitreous to resinous. Colour red brown, yellowish brown, to brownish black. Streak white or grey. Translucent to opaque. Fracture conchoidal, *Comp.* Silicate of alumina, iron, and magnesia, $(Fe, Mg)_3(Al_2)_6Si_6O_{33}$; frequently contains some manganese with water.

Pyr. BB infusible, except varieties rich in manganese, which fuse at 4 to a black magnetic slag. With the fluxes reacts for iron, sometimes also for manganese. Not materially affected by acids.

Loc. In argillaceous rocks under similar conditions to chiastolite. In talc schist at Bathurst.

87. TITANITE (*Sphene*). Monoclinic; crystals usually wedge-shaped; hemidomes, octahedral, and twinned tabular prisms. Also granular and compact. Cleavage prismatic tolerably perfect.

H 5—5·5. G 3·5. Lustre highly vitreous to resinous. Titanite proper is brown or black, sub-translucent to opaque· Sphene is yellow, greenish, or grey, transparent to translucent. Brittle.

Comp. Silicate of lime and titanium, $CaTiSiO_5$.

Pyr. BB changes colour, intumesces, and fuses at 3 to a brown or black glass. With the fluxes reacts for titanium. The saturated borax bead becomes enamel blue by flaming in the RF. The micro. salt bead is colourless in the OF, and yellow while hot, violet when cold in the RF. Partially dissolved by HCl; completely so by H_2SO_4. The hydrochloric solution boiled with a scrap of tinfoil turns violet.

Loc. Titanite has a considerable geological range, being found in plutonic, crystalline, metamorphic, and volcanic rocks, as well as in limestone and ironstone. It affects particularly the association of amphibole, as in hornblendic granite, hornblendic gneiss, syenite, phonolite, trachyte, and diorite, in which rocks it is a frequent accessory constituent. The crystals are usually wedge-shaped and of microscopic size. It would appear to be one of the earliest developed minerals, since it occurs endomorphous in most of the other minerals which compose the rocks above mentioned. Green titanite has been found in New England, N.S.W., and at Brown Hill, Macdonnell Range, S.A. Future investigation may prove that its distribution, at least as a rock-forming mineral, is not so restricted in Australian localities as would at present seem to be the case.

HYDROUS SILICATES.

PECTOLITE GROUP.

The minerals of this group are characterized by inferior hardness and specific gravity, as compared with the anhydrous silicates, easy fusibility, and the yielding of water when heated in the closed tube. They are completely decomposed in hydrochloric acid, and share with the anhydrous silicates the property of leaving a skeleton of silica when fused with micro. salt.

88. PECTOLITE. Monoclinic; six-sided prisms with planes of the hemidome; isomorphous with wollastonite. Commonly in bundles of parallel, divergent, or stellate acicular prisms, or in long fibres like tremolite. Cleavage orthodiagonal perfect.

H 5. G 2·68—2·78. Lustre somewhat silky or pearly. Colour white or greyish. Sub-translucent to opaque. Tough.

Comp. Hydrous silicate of lime and soda, $(H_2Na_2Ca)SiO_3$; often contains alumina, ferric oxide, and potash.

Pyr. BB fuses at 2 to a white enamel. Gelatinizes with HCl.

Loc. A decomposition product, chiefly perhaps of plagioclastic felspar, it is generally found deposited on joints and in druses of volcanic rocks and in limestone. Mt. Walker near Mudgee, N.S.W., in carboniferous limestone, near the contact with an intrusive dyke.

89. LAUMONTITE (*Laumonite*). Monoclinic; crystals resembling those of augite, four-sided prisms usually terminating in a prominent plane of the clinodome. Also

divergent columnar. Two perfect cleavages, clinodiagonal and prismatic.

H 3·5—4. G 2·25—2·36. Lustre vitreous to pearly. Colour white, or pale yellowish, greyish, reddish tints. Streak white. Transparent to translucent. Being very liable to decomposition (even in the sheltered situation of a mineralogical cabinet) it soon loses lustre on exposure, becomes opaque white, and crumbles to powder.

Comp. Hydrous silicate of lime and alumina, $H_4Ca(Al_2)Si_4O_{12} + 2 H_2O$.

Pyr. BB fuses with intumescence at 3 to a white enamel, colouring the flame brick red. Heated in the closed tube one-half of the water is expelled at a moderate heat, the other half only after prolonged exposure to a red heat. Gelatinizes with HCl.

Loc. Mostly found in association with vesicular volcanic rocks. Strathmore, Q.—With calcite in cavities of greenstone in the neighbourhood of Kiama; in soft grey shale at Cox River near Bathurst. Talbragar River, N.S.W.—Hampshire Hills, Western Tasmania.

90. PREHNITE. Rhombic; six-sided, often barrel-shaped prisms, with terminal planes perfect. Crystals somewhat rare; commonly globular, botryoidal, or stalactitic, superficially crystalline. Also granular, massive, sometimes pulverulent. Cleavage basal distinct.

H 6. G 2·8—2·95. Lustre vitreous, on cleavage planes resinous. Colour apple green, greyish green, greenish white. Streak white. Translucent. Strong double refraction. Fracture uneven. Pyro-electric.

Comp. Hydrous silicate of alumina, lime, and iron, $H_2Ca_2(Al_2,Fe_2)Si_1O_{12}$.

Pyr. BB fuses with intumescence at 2 to a vesicular enamel. In the hydrochloric solution the silica separates without being gelatinized; NH_3 throws down a precipitate of hydrate of alumina.

Loc. Occurs chiefly in greenstone, rarely in granite, syenite, and gneiss. Mostly derived from the decomposition of felspar, amphibole, or pyroxene, and has been observed pseudomorphous after analcite. In copper-bearing amygdaloidal greenstone at Strathmore Ck., Q.—Prospect Hill, Paramatta, in diorite. With copper ore in felspar porphyry at Reedy Ck., Gwydir River. Emu Ck., New England, N.S.W.—Amianth Place, S.A.

91. Apophyllite. Tetragonal; four-sided prisms, tabular, or nearly cubical, with vertical edges replaced, giving the crystal sometimes quite a cylindrical appearance; octahedra with replaced solid angles (resembling Fig. 30). Also laminar and massive. Cleavage basal eminent, octahedral perfect.

H 4·5—5. G 2·3—2·4. Lustre vitreous, on basal planes splendent pearly. Colour white, yellowish, greenish, greyish, pink. Streak white. Transparent. Brittle.

Comp. Hydrous silicate of lime and potash, with some fluorine, $4\,(H_2CaSi_2O_6) + KF$.

Pyr. BB swells and fuses at 1·5 to a white enamel, colouring the flame violet. The water condensed in the closed tube has an acid reaction. Fused with micro. salt in the open tube liberates hydrofluoric acid.

Loc. Occurs under similar conditions to prehnite. Murrurundi railway tunnel, Liverpool Range; Vegetable Creek; Talbragar River, east of Dubbo, N.S.W.

ZEOLITE GROUP.

The zeolites are chemically and crystallographically allied to the felspars and pyroxenes, with the important difference that they are non-magnesian and hydrous. The amount of water they contain varies in different species from 4 to 22 per cent. Part of this water is chemical bound (basic), part is water of crystallization, and part is in some instances merely hygroscopic. They are always secondary products arising from the alteration of felspar and other aluminous silicates, and are most commonly met with in cavities and fissures of volcanic and trappean rocks. Most of them fuse with ebullition (*zeo*, to boil), and all gelatinize in hydrochloric acid. Owing to the small amount (rarely exceeding 1·5 per cent.) of colouring oxides present in zeolites their streak is always uncoloured.

92. NATROLITE. Rhombic; slender acicular prisms terminating in pyramidal planes; often in divergent or stellate groups. Also fibrous and granular.

H 5—5·5. G 2·2. Lustre vitreous to silky. Colour white, greyish, yellowish, or reddish; sometimes colourless. Transparent to translucent.

Comp. Hydrous silicate of alumina and soda, $Na_2(Al_2)Si_3O_{10} + 2\ H_3O$; frequently contains ferric oxide, which imparts the colour.

Pyr. BB becomes opaque white, and fuses quietly at 2 to a colourless glass. Gelatinizes completely in acids. In the hydrochloric solution HN_3 produces a precipitate of hydrous alumina.

Loc. In volcanic rocks at Ipswich, Toowoomba, Peak Downs, Q.—Murrurundi, Liverpool Range; Inverell; Lord Howe Island, N.S.W.—Common in the basalt of Phillip Island, Vic.—With calcite in amygdaloidal volcanic rock in the neighbourhood of Dunedin, N.Z.

93. SCOLECITE. Monoclinic; prisms, terminal plane of the hemidome indistinct. Fibrous, radiating; sometimes nodular.

H 5—5·5. G 2·2—2·4. Lustre vitreous to silky. Transparent to translucent. Pyro-electric.

Comp. Hydrous silicate of alumina and lime, $Ca(Al_2)Si_3O_{10} + 3\ H_2O$.

Pyr. BB curls up, and fuses with intumescence at 2 to a vesicular translucent glass. Gelatinizes completely in acids. In the hydrochloric solution from which the alumina has been separated by NH_3, oxalic acid throws down a white precipitate of oxalate of lime.

Loc. Emu Creek, New England, in basalt.—In greenstone at Yackandandah; in granite at Elphinstone, Vic.

94. MESOLITE. Triclinic; always in twinned prisms with vertical planes of composition. In tufts of fragile slender fibres; commonly in minute spheroids with downy or crystalline surfaces.

H 5. G 2·2—2·4. Vitreous or silky. Colour white, greyish, or yellowish; sometimes colourless.

Comp. Hydrous silicate of alumina, lime, and soda, $(Ca, Na_2)(Al_2)Si_2O_{10} + 3\ H_2O$.

Pyr. BB yellow flame coloration. Otherwise like scolecite.

Loc. Common in the basalt of Richmond, near Melbourne. Also found at Clunes, Vic.—Hellyer River, Tas.

95. ANALCITE. Isometric; icositetrahedron (Fig. 21), or combinations of that form and the cube (Fig. 38). Might easily be mistaken for leucite, which occurs in the same form and often in the same kind of rock.

H 5—5·5. G 2·22—2·29. Lustre vitreous. Colour white, or with a faint tinge of yellow, red, or green; also colourless. Transparent to translucent. Fracture uneven. Brittle.

Comp. Hydrous silicate of alumina and soda, $Na_2(Al_2)Si_4O_{12} + 2\ H_2O$.

Pyr. BB whitens and fuses quietly at 2·5 to a clear glass, colouring the flame yellow. In HCl gelatinizes, but less completely than scolecite. NH_3 produces a precipitate of hydrate of alumina.

Loc. Strathmore Ck. and Peake Downs, Q.—Inverell, Gulgong, Talbragar River, N.S.W.—Abundant in the older basalt of Phillip Island and Flinders; scarce in the newer basalt of Richmond, Vic.

96. CHABAZITE. Hexagonal; primary form a rhombohedron, closely approximating the cube; six-sided pyramids with or without prism; hemihedral (rhombohedral and scalenohedral) terminations. Usually twinned. Cleavage rhombohedral imperfect.

H 4—5. G 2·1—2·19. Lustre vitreous. Colour white, reddish. Transparent to translucent. Fracture uneven. Brittle.

Comp. Hydrous silicate of alumina, lime, and potash; usually also some soda, $(H_2K, Na)_2Ca(Al_2)Si_5O_{16} + 6\,H_2O$. Lime considerably in excess of alkalies.

Pyr. BB fuses at 2 with intumescence to a white enamel. With HCl like analcite.

Loc. Toowoomba, Peake Downs, Q.—Common in the basalts of New South Wales: Murrurundi, Liverpool Range; Muswellbrook, Hastings River, Reedy Ck., Coroo, Tamworth; Dapto and Robertson, Illawarra district.—Pentland Hills, east of Ballan; Clunes, Malmsbury. In granite at Frankston, Vic.—Lefroy, Sheffield, Springfield, Hellyer River, Mt. Pelion, Tas.—Townbelt, Dunedin, N.Z.

Var. (*a*) *Herschelite.* Six-sided tables, six-sided pyramids, always twinned. Poor in lime, sometimes altogether free from it.

(*b*) *Phacolite.* Obtuse double six-sided pyramids; always macled. Often so flattened as to become lens-shaped (*phacos*, lens). Richmond, Vic.—Sheffield, Emu Bay, Tas.

(*c*) *Seebachite.* Flat hexagonal pyramids with rounded apex, divided into six sectors; always twinned. Colourless. *Comp.* $(CaNa_2)\,(Al_2)Si_4O_{12} + 6\,H_2O$. This variety is restricted to the basalt of Richmond and Collingwood, Vic.

97. GMELINITE. Hexagonal; six-sided prisms surmounted by acute truncated pyramids; also octahedral with faces of the rhombohedron. Not known to occur in twins. Cleavage prismatic perfect. The faces of prisms often horizontally striated, like quartz.

H 4·5. G 2·04—2·17. Lustre vitreous. Colourless, white, yellowish, greenish, reddish. Transparent to translucent.

Comp. Hydrous silicate of alumina, lime, and soda, $(Na_2Ca)\,(Al_2)Si_4O_2 + 6\,H_2O$; frequently contains some potash. Alkalies considerably in excess of lime.

Pyr. BB fuses at 3 to a white enamel. Otherwise like scolecite.

Loc. Inverell, Liverpool Range, Tamworth, N.S.W. —Phillip Island and Flinders, Vic.

98. PHILLIPSITE. Monoclinic; four-sided prisms surmounted by pyramids, somewhat resembling tetragonal forms. Always in penetration twins, generally double, and crossing under right angles. Clinodiagonal faces finely striated. Often in groups of divergent acicular crystals.

H 4—4·5. G 2·2. Lustre vitreous. Colourless, white. Transparent to opaque.

Comp. Hydrous silicate of alumina, lime, and potash, $(CaK_2)(Al_2)Si_4O_{12}+4\,H_2O$; frequently with some soda (specimens from Richmond contain as much as 5·1 per cent.).

Pyr. BB crumbles and fuses at 3 to a white enamel. Gelatinizes perfectly in HCl.

Loc. Abundant and finely crystallized in the newer pliocene basalt of Richmond and Collingwood near Melbourne; also met with at Clunes and Kyneton, Vic.—Hellyer River, Tas.

The composition of the three last species may be theoretically set down as under—

	SiO_2.	Al_2O_3.	CaO.	Na_2O.	K_2O.	H_2O.
96. Chabazite . . .	47·3	20·4	8·0	1·2	1·8	21·3
96^a. Herschelite . . .	47·9	20·5	—	9·3	4·7	17·6
96^c. Seebachite . . .	44·9	22·0	7·1	4·6	0·9	20·2
97. Gmelinite . . .	46·0	19·7	3·6	4·0	6·0	20·7
98. Phillipsite . . .	47·9	20·5	7·4	—	6·3	17·9
do. (from Kyneton)	46·2	23·4	4·5	5·1	6·3	14·5

It is to be noted, however, that the percentage ratio varies considerably in specimens from different localities, and that there are intermediate varieties in which the amount of lime and alkalies seems to establish a relation now with the one and then with the other type, and the true crystallographic position of which is still the subject of discussion.

99. STILBITE (*Desmine*). Monoclinic; clinopinacoids terminating in truncated pyramids; occasionally penetration twins resembling those of phillipsite. Commonly in radiating groups of slender crystals; in bundles often contracted in the middle like sheaves; globular with stellate structure (*sphero-stilbite*). Cleavage clinodiagonal perfect, orthodiagonal imperfect.

H 3·5—4. G 2·1—2·2. Lustre vitreous, on cleavage planes pearly. Colour white, yellowish, brownish, reddish. Transparent to translucent. Fracture uneven. Brittle.

Comp. Hydrous silicate of alumina and lime, $H_4Ca(Al_2)Si_6O_{18} + 4\,H_2O$. Soda or potash, or both, are usually present, but the aggregate amount rarely exceeds 2 per cent.

Pyr. BB swells up, and fuses at 2 with intumescence to a white glass. Flame coloration brick red. From the hydrochloric solution silica separates as an imperfect jelly; NH_3 throws down hydrous alumina; oxalic acid precipitates oxalate of lime.

Loc. Blackgin Ck., west of Rockhampton; Toowoomba, Q., in basalt.—Gunnedah, Tenterfield, Tamworth, Gulgong, Carroll; in metamorphic slate at Adelong, N.S.W.—Emu Plains, Mersey River, Tas., in a vein in palæozoic country.

100. HEULANDITE. Monoclinic; stout four or six-sided prisms, the lateral edges replaced by planes of the orthodome; clinopinacoids and basal planes generally intact. Sometimes in spheroids. Cleavage clinodiagonal highly perfect.

H 4. G 2·2. Lustre vitreous, on cleavage faces pearly. Colour white, grey, yellowish, brownish, reddish. Transparent to translucent. Fracture uneven. Brittle.

Comp. Hydrous silicate of alumina and lime, $H_4Ca(Al_2)Si_6O_{18} + 3\,H_2O$, usually with a small amount of soda or potash.

Pyr. Like stilbite.

Loc. Hartley, N.S.W., reddish crystals in clefts of sandstone.—In aggregates of yellowish crystals in fissures of

Silurian sandstone, Maldon; similarly on the wall rock of Maxwell Reef, Inglewood; on joints of granite, Frankston, Vic.

TALC GROUP.

The minerals of this group are foliated or amorphous magnesian silicates, more or less hydrated. They have a greasy feel, and are highly refractory.

101. TALC (*Steatite*). Rhombic (? Monoclinic); six-sided thin plates, sometimes in stellate aggregates. Commonly foliated, also globular, cryptocrystalline, and massive. The names *steatite*, *soapstone*, *French chalk* apply to the massive varieties. Cleavage basal highly perfect.

H 1—1·5. G 2·6—2·8. Lustre pearly. Colour white, silvery white, pale green. Steatite has often a grey, brown, red, or mottled appearance, from oxide of iron or other impurities. Streak white, or lighter than the colour. Translucent to opaque. Sectile. Laminæ flexible but non-elastic.

Comp. Silicate of magnesia with some basic water, $H_2Mg_3Si_4O_{12}$. Steatite usually contains some alumina, protoxide of iron, lime, etc.

Pyr. BB exfoliates and becomes opaque white. Thin foliæ fuse at 6; steatite is infusible. With cobalt solution turns pink. In closed tube, after prolonged heating, yields water. Not affected by HCl, slightly attacked by H_2SO_4.

Loc. Talc is usually associated with serpentine; it is an important constituent of talc schist, and as steatite forms an independent rock. It often results from the decomposition of olivine, amphibole, and pyroxene, and then usually contains alumina. It occurs pseudomorphous after quartz, the latter having no doubt been changed into amorphous silica and then taken up magnesia. Steatite occurs at Charters Towers, Ravenswood, Herberton, Kilkivan; Petrie's Quarry, Brisbane; Clifton Colliery, Darling Downs, Q.

—Foliated talc in six-sided plates at Gudgeby River, Urambeen, Bathurst, Gundagai, Newbridge, Barrier Range; steatite at Cow Flat, Bathurst, Tenterfield, Elsmore, Trunkey, N.S.W.—Strathloddon, pseudomorphs after quartz; talc schist in the Omeo district, and in the metamorphic country south of Balmoral, Vic.—Foliated at Kaiserstuhl, and Jane Valley; massive at Menge Town, Barossa, Moonta, Gumeracha, Jamestown, S.A.—Arthur River, south of Campbell Range; Clayton Rivulet; Trial Harbour, Meredith Range, Heazlewood, Asbestus Range near Beaconsfield, Tas.—Head of Richenda River, Kimberley, Stirling Range, W.A.—Moonlight Ck., Wakatipu; Collingwood, Nelson, N.Z.—Balade nickel-mine, Yate, New Caledonia.

102. SEPIOLITE (*Meerschaum*). Amorphous; compact with clay-like texture.

H 2. G 0·9—1; dried at a temperature under 100° C. floats on water. Lustre dull earthy; scratch shining. Colour white, yellowish, greyish, reddish. Opaque.

Comp. Hydrous silicate of magnesia, $Mg_2Si_3O_8 + H_2O$.

Pyr. BB infusible, thin splinters fusible at 6. Yields much water in the closed tube. With cobalt solution becomes pink. Gelatinizes in HCl.

Loc. In connection with serpentine rocks occurs in Asia Minor, Greece, Spain. Not known to occur in Australasia.

103. SERPENTINE. Amorphous, sometimes in pseudomorphs. Compact, granular, cryptocrystalline, foliated, laminated, fibrous.

H 2·5—4. G 2·3—2·6. Lustre feebly resinous, greasy, waxy, earthy. Colour various shades of green, greenish yellow, greenish black, brown, red, purple, mottled, striped. Streak white, or paler than the colour. Translucent to opaque. Fracture sub-conchoidal, splintery, earthy.

Comp. Hydrous silicate of magnesia, $H_2Mg_3Si_2O_8 + H_2O$, usually with some oxide of iron, and from 2 to 3 per cent., in the aggregate, of the following—Na_2O, K_2O, MnO, NiO, Cr_2O_3, and Al_2O_3.

Pyr. F 5—6. Decomposed by acids.

Var. *Precious serpentine;* bright oil green, translucent, H 2·5.

Common serpentine, serpentine rock; dark green, greenish black; often with red spots of ferric hydrate.

Ophiolite (*Verd antique*); a veined or mottled serpentine rock, containing calcite, aragonite, dolomite, or magnesite, which impurities impart to it sometimes a porphyritic appearance (*serpentine porphyry*).

Retinolite; lustre resinous or waxy; colour pale green or greenish yellow.

Chrysotile; asbestiform with silky lustre, greenish white or light green.

Baltimorite; a variety of chrysotile, with silky fibre like amianthus, found in Maryland and Canada, North America, whence it is largely entered on the market under the name of "asbestus" (*vide* Asbestus).

Picrolite; columnar or coarsely fibrous, sometimes bladed, the fibres or blades not readily separable. Colour various shades of green, brown, grey, or red.

Marmolite; greenish white or pale green; thinly foliated, the foliæ easily separated.

Serpentine schist, Williamsite, Antigorite; stratiform, laminar, slaty, usually contains much alumina, and sometimes free quartz.

Most of these varieties lack stability of composition and homogeneity, and are to be regarded as rocks rather than minerals. Under the microscope serpentine presents a network of veins and laminæ, the latter often consisting of olivine, enstatite, non-aluminous amphibole, or pyroxene, clearly showing its derivation. The composition of serpentine depends, therefore, in the first place on the nature of the parent mineral, and in the next place on the extent of the alteration which that mineral has undergone (incomplete or complete "serpentinization"). Serpentine occurs pseudomorphous after dolomite, brucite, mica, and chlorite, and in turn yields brucite, magnesite, siderite, limonite, magnetite, chromite, quartz, and opal, usually coloured by oxide of iron, manganese, chromium, or nickel. Chromite is derived from picotite and diopside; magnetite from the ferric oxide or silicate of iron originally contained in the rock; the nickel is partly or wholly attached to the magnetite and pyrrhotite of the serpentine. Olivine rock has perhaps most largely contributed to the formation of massive serpentine and retinalite; the origin of marmolite, serpentine schist, and other fissile varieties may be looked for in amphibolite or hornblende schist; fibrous kinds (chrysolite, picrolite) may have been derived from tremolite or talc schist. Finally, bastite (see under), judging from its cleavage, is probably an alteration product of enstatite or hypersthene.

Loc. Kilkivan, precious serpentine and chrysotile; Tinaroo, precious serpentine and picrolite; common serpentine at Wheeler Range west of Rockhampton, Gladstone, Ipswich; Sandy Ck. and Mt. Coora in the Burnett district, Q.—Common serpentine at Bingera, Warialda, Barraba, Nundle, Jones Ck. near Gundagai, Clarence River, Young, Orange, Dungog. Chrysotile at Gundagai, Lucknow, Barraba. Serpentine schist at Tuena, Middle Ck., Jocelyn. Picrolite at Kelly's Ck., Gwydir River, Wentworth. Marmolite at Cowarbee near Wagga. Ophiolite at Apsley, Manning, Hastings, and Peel Rivers, N.S.W.—Serpentine rock and chrysotile at Mt. Timbertop, Mt. Wellington, Gippsland. Picrolite at the Hummocks, Wando River, north of Casterton, Vic.—Iron Nob, west of Port Augusta; Tumby Bay, Port Lincoln, Sailor's Gully, Gumeracha. Ophiolite at Mt. Crawford, S.A.—Common serpentine and serpentine schist at Anderson's Ck. west of Beaconsfield, Heazlewood, Trial Harbour, Pieman, Mt. Claude, Mt. Ramsay. Chrysotile, Yorktown, Dundas. Purple-coloured serpentine rock, retinolite, marmolite, and picrolite at Dundas, Tas.—Wooded Peak, Champion Mine, Aniseed Valley, Dun Mountains, and other places in Nelson. Slaty serpentine, Kamo, north-east of Auckland, N.Z.—Common in the southern part of New Caledonia.

104. BASTITE (*Schiller spar*). Rhombic (?); foliated. Cleavage basal perfect; usually also two rhombic prismatic cleavages.

H 3·5—4. G 2·6. Lustre pearly, metallic, bronze-like. Colour various shades of green, to brown.

Comp. Hydrated silicate of magnesia and iron, $H_2(MgFe)_3Si_2O_8 + H_2O$; generally contains alumina, lime, and alkalies, frequently also chromium and manganese.

Pyr. F 5—6. With the fluxes reacts for iron. The water deposited in the closed tube gives with test-papers reaction for ammonia. Decomposed by acids.

Loc. Bastite may be looked upon as a serpentinized rhombic pyroxene (enstatite or hypersthenite) whose original cleavage it has retained, while it has acquired an additional cleavage (foliation). Mt. Wheeler, west of Rockhampton, Q.—Barraba, Bingera, N.S.W.—Mt. Timbertop, Vic.—Dundas, Heazlewood, Parson's Hood Mountain, Tas.—Dun Mountains, N.Z.—New Caledonia.

105. SAPONITE (*Soapstone*). Amorphous; earthy, nodular.

H 1 when dried, soft-soaplike when *in situ*. G 2·27. Lustre and touch unctuous. Colour white, yellowish, reddish, greenish, bluish, and mottled.

Comp. Hydrous silicate of magnesia and alumina, MgO, Al_2O_3, $SiO_2 + H_2O$, usually with some Fe_2O_3, CaO, Na_2O, K_2O.

Pyr. BB blackens and fuses at 6. Scarcely acted upon by HCl; decomposed by H_2SO_4.

Loc. Usually occurs in cavities of serpentine and trappean rocks. Icely, Williams River, Lowie, N.S.W.—Mt. Strathloddon, Vic., forms a thin vein in Silurian shale beneath a capping of auriferous drift.—New Caledonia, in serpentine.

106. SMECTITE (*Fuller's Earth*). Amorphous; clay-like.

H under 1. G 1·9—2·1. Lustre dull, but shining when rubbed. Colour white, grey, green, brownish. Feel soapy.

Comp. Hydrous silicate of alumina and magnesia, $H_4(Al^2)$

$MgSi_3O_{12} + 4\ H_2O$, with some iron and lime. Contains from 25 to 35 per cent. of water. Impure varieties pass into kaolinitic clay, which contains only half that amount of water.

Pyr. F 4—5. Decomposed by HCl. In water becomes soft and pasty.

Loc. Fuller's earth forms an important part of a group of argillaceous strata some 150 feet in thickness in the lower oolite of England. It is rarely found pure. On account of its grease-absorbing properties it has been employed in the scouring of wool, and is used as an hygienic agent.

107. GLAUCONITE (*Green Earth*). Amorphous; granular or earthy.

H 2. G 2·2—2·4. Lustre sub-resinous to dull. Colour olive green, greyish green to greenish black. Opaque.

Comp. Hydrous silicate of iron, alumina, and potash, K_2O, FeO, Al_2O_3, Fe_2O_3, $SiO_2 + H_2O$; the earthy .variety (green earth) is richer in alkaline bases—K_2O, Na_2O, MgO, FeO, Al_2O_3, $SiO_2 + H_2O$.

Pyr. BB fuses at 2·5 to a black magnetic slag. Mostly decomposed by HCl.

Loc. Glauconite in a granular form constitutes an essential part in the "greensand" of cretaceous and old tertiary strata. The earthy variety (green earth) is met with in cavities of eruptive rocks, where it results from the decomposition of pyroxene, amphibole, chlorite, etc. Glauconite occurs in eocene deposits at Aldinga, Bunda, Port Lincoln, Ilesford, and elsewhere on the South Australian coast. In the Buller and Amuri series of the cretaceo-tertiary formation of New Zealand.

KAOLIN GROUP.

The minerals of this group are essentially hydrous silicates of alumina. They yield water in the closed tube, and when moistened with cobalt solution and ignited afford a blue mass.

108. KAOLINITE. Rhombic; in rhombic or six-sided scales; usually in compact, clayey, or earthy masses, which, when examined with the magnifier, prove to be made up of scaly aggregates. Cleavage basal perfect. The individual scales often show interrupted striations parallel to their edges.

H 1—2. G 2·4—2·6. Lustre pearly to dull. Colour white, but often stained by metallic oxides. Scales translucent, flexible, but non-elastic. Feel, when dry, greasy. Moist becomes plastic.

Comp. Hydrous silicate of alumina, $H_2(Al_2)Si_2O_8 + H_2O$. Usually contains 13·9 per cent. of water; impure varieties 15 to 16 per cent. of water, besides variable amounts of lime, magnesia, oxide of iron, and alkalies.

Pyr. Infusible. Insoluble in acids. Calcareous and alkaline varieties fuse at from 4 to 6. At a red heat loses its water of constitution permanently, and when subsequently moistened with water is not again rendered plastic.

Loc. Kaolinite, as stated above, is, even in its massive form, wholly made up of scales. A variety occurring in pearly, often fan-shaped scaly aggregates is called *nacrite*. When in a granular or earthy condition it is no longer an homogeneous substance, and is best described as *kaolinitic clay*. As such it forms the base of all clays, shales, and slates. Kaolinite results from the decomposition of felspars and other aluminous silicates, by a process which has been explained under orthoclase (*q. v.*). The purer kinds are usually met with in granite and gneiss. All felspathic rocks are, however, liable to weather into clays. Thus common basalt in the course of decomposition loses 66 per cent. of its silica, 90 per cent. of its peroxide of iron, 50 per cent. of its lime, 9·6 per cent. of its magnesia, and 83 per cent. of its potash and soda, or in the aggregate 43 per cent. of its bulk. The alumina alone remains undiminished, while some 12 per cent. of water is taken up. In most cases the detrital matter resulting from the disintegration and decomposition of aluminous silicates is liable to be carried away by water, and re-deposited in valleys or other depressions. Sometimes, however, the original rock is decomposed *in situ:* masses of granite may become kaolinized to a greater or lesser depth beneath the surface; the basalt or greenstone filling veins and dykes are converted into *wacke;* sheets of volcanic rock rich in iron oxides pass into *laterite* (red basaltic clay). Those mineral constituents which have resisted decomposition, especially quartz, will as a rule be found in the clays. Thus in Cornwall the china clay, which has been produced by the decomposition *in situ* of massive granite, has to be quarried. The kaolin of Meissen (used in the manufacture of Dresden china) has its origin in weathered gneiss. The refractoriness of a clay is lessened by the presence of alkaline ingredients. The change of colour which most clays undergo by heating is chiefly due to oxide of iron.

Kaolinite and kaolinitic clay occur at Stanthorpe and Heberton in stanniferous granite; in dykes of eruptive rock at Mt. Morgan, Q.—Lambing Flat, Barraba, Uralla, Gulgong, Broken Hill, N.S.W.—Great Western, Black Range near Stawell, Lal Lal, Dunolly, Bulla Bulla, in granite country. Nacrite in seams in "selwynite" at Heathcote, Vic.—Wallaroo, Tanunda, Charlotte Waters, Port Vincent, S.A.—Flinders Island, Piper River, Killicranki Bay, Mt. Bischoff, Blue Tier, Tas.—Abundant in the granite tracts of Western Australia.

109. PHOLERITE. Rhombic; in four and six-sided plates, like kaolin; usually in compacted aggregates.

H 1—2·5. G 2·4. Lustre pearly to dull. Colour white, greyish, greenish, yellowish. Translucent to opaque. Feel unctuous.

Comp. Hydrous silicate of alumina, $H_2(Al_2)_2Si_3O_{13} + 2\ H_2O$. Contains 15·7 per cent. of water.

Pyr. Like kaolin.

Loc. Occurs in crevices and on walls of mineral veins, generally resulting from the decomposition of felspar. In scaly aggregates and matted films in and adjoining auriferous quartz veins at Bendigo, Steiglitz, Egerton, Vaughan, Vic.

110. HALLOYSITE. Amorphous; clay-like, earthy.

H 1—2. G 1·8—2·4. Lustre waxy to dull. Colour white, yellowish, greenish, reddish, bluish, and black. Translucent to opaque. Fracture conchoidal.

Comp. Hydrous silicate of alumina, $(Al_2)Si_2O_7 + 4\ H_2O$. Contains 19 per cent. of water. Often with Fe_2O_3, CaO, MgO, K_2O, and Na_2O.

Pyr. Decomposed by HCl. Placed in water its translucency increases to transparency; absorbs water without becoming plastic. In other respects like kaolinite.

Loc. A decomposition product, like pholerite, of felspar and other aluminous silicates, it occurs generally on joints of felspathic rocks and in mineral veins. Biggenden, Q., in bismuth lodes.—Berrima, of black colour; Murrurundi in cavities of amygdaloidal rock; Stony Ck., Wynyard, Carcoar, Lachlan, N.S.W.—John's Tunnel Mine, Moondarra, coloured green by silicate of copper; in auriferous veins at Wood's Point, Walhalla, Alexandra, Lauriston, Vic.—In silver-lead lodes at Zeehan, Dundas, Heazlewood, and Whyte River; an alteration product of schorl in stanniferous granite, Ben Lomond, Tas.—Yate, New Caledonia.

Var. Lithomarge. H 1. Greasy lustre and feel. Occurs in stanniferous greisen at Jinjellic; in the copper lode at Blayney, N.S.W.—Woah Harop and Llanberris Mines, Ballarat East, with albite, dolomite, and calcite.—Blue Tier, in granite; with copper ore at Mt. Lyell, Tas.

111. PYROPHYLLITE. Rhombic; no distinct crystals. Foliated, usually in radiating or stellate groups of plates. Also compact. Cleavage basal very perfect.

H 1—2. G 2·7—2·9. Lustre pearly, like talc; when massive dull. Colour white, greenish, yellowish, sometimes pale golden yellow. Translucent to opaque. The laminæ flexible but non-elastic. Feel unctuous.

Comp. Hydrous silicate of alumina, $(Al_2)Si_3O_9 + H_2O$, usually with some magnesia, lime, and ferric oxide.

Pyr. BB exfoliates and fuses at 6. Otherwise like kaolinite.

Loc. On joints in aluminous rocks. Forms the main constituent of certain kinds of clay slate (pencil slate), which are sometimes mistaken for talcose slates. Jones Ck. near Gundagai, N.S.W.—In clefts of slaty diorite at Golden Mountain, Doon; on phyllite, New Mariners Mine, Steiglitz; on joints of stanniferous granite, Beechworth. —Waratah, Oatlands, Table Cape, Tas.

112. Pinite. Amorphous; cryptocrystalline. Pseudomorphous after felspar, mica, talc, etc., and then often retaining the cleavage of the parent mineral.

H 3. G 2·6—2·8. Lustre waxy. Colour greyish white, greyish green, brownish, reddish. Translucent to opaque.

Comp. Hydrous silicate of alumina and potash, $H_6K_2(Al_2)Si_5O_{20}$; usually contains Fe_2O_3, FeO, MgO,·CaO, Na_2O, the aggregate amount of which ranges between the wide limits of 1 and 13 per cent.

Pyr. F 3—5·5. The water expelled by heating in the closed tube is alkaline. Partly decomposed by concentrated HCl.

Loc. Of bluish-green colour in serpentine, Hanging Rock, N.S.W.—In metamorphic slate, Stawell; Eaglehawk Reef, Bendigo, Vic.

Var. Agalmatolite (also called *pagodite*, in allusion to its use by Chinese and Indians as a material for carving figures and ornaments); massive, compact. H 2—2·5. Contains much iron and some basic water. Occurs in chlorite schist at Nurembla, Callalia Ck., N.S.W.—In nodular concretions in basalt, Gisborne, Keilor, Vic.

113. Cimolite. Amorphous; clay-like or earthy.

H 1 or less, G 2·2. Lustre unctuous. Colour white, greyish, yellowish, reddish. Opaque. Feel harsh like chalk. Adheres to the tongue.

Comp. Hydrous silicate of alumina, $(Al_2)Si_4O_{11} + 3\ H_2O$, usually with a slight addition of lime and magnesia.

Pyr. BB at first darkens, but on further heating becomes dull white. A light porous substance from Wyrallah, Richmond River, N.S.W., locally called "meerschaum," has been referred to the species cimolite. It forms a deposit of some extent, and encloses fossil leaves.

114. PALAGONITE. Amorphous; in grains and compact.

H 4. G 2·5. Lustre resinous, pitch-like. Colour yellow, red, brown, or black. Streak lighter than the colour.

Comp. Hydrous silicate of alumina, iron, and various protoxide bases, approximately $(H_2K_2NaMgCa)(Al_2Fe_2)Si_3O_{10} + H_2O$.

Pyr. BB fuses at 2 to 3 to a black magnetic slag. Decomposed by HCl, the silica separating as an imperfect jelly.

Loc. Palagonite (so called from a district in Sicily) has probably been produced by the action of heated vapours upon liquid lava or tufa. Its composition is so exceedingly variable—according to the different constitution of the rock from which it has been derived—that it can hardly be considered a true mineral species. Volcanic tuff, consisting to a large extent of palagonite, occurs in several of the volcanic districts of New Zealand. In Australia it has been observed at Tangil, South Gippsland, Vic., where a narrow lava floe, in places 60 to 80 feet in thickness, overlies the auriferous gravel drift of an ancient stream bed. The bottom part of this lava sheet is made up of a brecciated mass of wacke, glassy basalt, black pitchstone—like palagonite, sphero-siderite, and limonite.

115. SELWYNITE. Amorphous; compact, massive, or finely granular.

H 3—4. G 2·5. Lustre waxy to dull. Colour emerald green, greyish, and bluish green. Streak greenish white.

Sub-translucent to opaque. Fracture uneven, inclined to splintery. Somewhat brittle.

Comp. Hydrous silicate of alumina, chromium, and magnesia, approximately $Mg(Al_2Cr)_2Si_3O_{13} + H_2O$.

Pyr. BB whitens and fuses at 5·5 to a grey vesicular glass. With the fluxes reacts for chromium. Partly decomposed by HCl.

Loc. Occurs in the Mt. Ida Range, near Heathcote, in the form of dykes in Upper Silurian slate. It is traversed by thin seams of a white scaly substance like nacrite. Selwynite is probably a decomposition product of diorite which originally contained chromite.

116. ALLOPHANE. Amorphous; botryoidal, mammillary, stalactitic, encrusting, sometimes powdery.

H 3. G 1·87. Lustre vitreous, resinous to dull. Colour pale blue, green, brown, white, colourless. Streak white. Fracture uneven. Brittle.

Comp. Hydrous sub-silicate of alumina, $(Al_2)SiO_5 + 5\ H_2O$. Frequently contains trifling amounts of lime, magnesia, and iron; sometimes traces of copper, to which the blue and green colours are due.

Pyr. BB infusible, but crumbles. Gelatinizes with HCl.

Loc. Allophane is, like kaolin, a decomposition product of felspar and other aluminous minerals. In copper veins, Blayney, N.S.W.—In an auriferous quartz vein, Hampshire Reef, Stawell, Vic.—In miocene strata, near Mt. Schank, S.A.—In serpentine, Harman's Rivulet, and in the neighbourhood of Derby, Tas.—Kunie Island, south of New Caledonia.

CHLORITE GROUP.

The minerals of this group are essentially hydrous silicates of alumina, magnesia, and iron. They are soft and eminently cleavable, the cleavage plates flexible but not elastic. Colour various shades of green; in polarized light often brilliantly blue and brown, and sections parallel to the principal crystal axis exhibit distinct dichroism. Some magnesian silicates, *e.g.* augite, hornblende, olivine, serpentine, yield on decomposition a green translucent scaly chlorite-like substance, to which petrographers have given the name ***viridite.***

117. CHLORITE (*Prochlorite*). Hexagonal (Monoclinic ?). Foliated, with perfect basal cleavage; the plates often arranged in fan shape.

H 1—2. G 2·8. Lustre on basal planes sub-resinous, otherwise dull. Colour bright green to greenish black. Translucent in thin foliæ; opaque.

Comp. Hydrous silicate of alumina, magnesia, and iron, $H_4(Mg, Fe)_4(Al_2)Si_2O_{14}$. The water is mostly, if not wholly, basic.

Pyr. BB whitens, and sometimes exfoliates; thin plates fuse at 5·5 to a grey glass. With the fluxes reacts for iron, and sometimes for chrome. Yields water in closed tube. Decomposed by H_2SO_4.

Loc. Occurs in crystals implanted in granite, gneiss, serpentine, etc. Evenly distributed through argillaceous rocks constitutes chlorite schist. Gulgong, Queenbeyan, Nymagee, Orange, N.S.W.—In quartz, Little Bendigo; in Silurian slate, Haddon near Ballarat.—Mt. Lofty, Gawler Range, Sealand Valley, S.A.—Mt. Ramsay, Heemskirk, Tas.—Chlorite schist at Upper Murchison, Northampton, Roeburne, Kimberley, W.A.— Foliated schists in part chloritic occur throughout the elevated parts of Otago, N.Z. In some of the localities just mentioned the mineral may belong to clinochlorite (*q. v.*).

118. CLINOCHLORITE (*Repidolite*). Monoclinic; in plates, rarely in domes; usually in scales; also granular and earthy. Basal cleavage perfect.

H 2—2·5. G 2·7. Lustre dull, on cleavage planes inclined to pearly. Colour bright green, greyish green, sometimes pink. Streak white or greenish. Strongly dichroic. Transparent to translucent.

Comp. Hydrous silicate of alumina, magnesia, and iron, $H_8(Mg, Fe)_6(Al_2)Si_3O_{19}$.

Pyr. Like chlorite.

Loc. Tinaroo, Q., in stanniferous granite.—Emmaville, Oberon, Glen Ck., Mole Tableland, in granite, N.S.W.—In auriferous quartz veins at Castlemaine and Vaughan, Vic.—Blue Tier, Ben Lomond, Bell Mount, Tas. The mineral in some of these localities may be in part prochlorite (*ante*).

Other chloritic minerals are—

Pyrosclerite; rhombic. $(Mg, Fe)_6(Al_2Cr_2)Si_4O_{17} + H_2O$.

Chloritoid; monoclinic or triclinic. $(Mg, Fe)_5(Al_2)Si_4O_{16} + H_2O$.

Pennite; hexagonal. $H_{10}(Mg, Fe)_7(Al_2)Si_4O_{23}$.

ALUMINA AND ALUMINATES.

These minerals possess considerable hardness, are infusible, slowly but completely soluble in micro. salt, and yield a blue mass when heated with cobalt solution.

119. **CORUNDUM.** Hexagonal; commonly rhombohedron, scalenohedron, hexagonal prism and pyramid; faces of crystals often rough. Also granular, compact, and pulverulent. Cleavage basal imperfect.

H 9. G 3·9—4·1. Lustre vitreous, on cleavage planes pearly; sometimes opalescent. Colour red, blue, green, yellow, brown, grey, white. Transparent to opaque. Fracture uneven. Tough. Frictio-electric.

Comp. Alumina, Al_2O_3, often contains minute quantities of CaO, SiO_2, and Fe_2O_3.

Pyr. Infusible. Slowly soluble in micro. salt, which, except in the case of ferriferous varieties, remains uncoloured. Not affected by acids.

Loc. Corundum occurs granular in gneiss, granite, mica, and chlorite schists, dolomite, limestone, etc., but is more commonly found in the detritus of these rocks in the form of rolled fragments, or semi-rounded crystals.

Var. (*a*) *Ruby* (*Oriental ruby*, *Ruby sapphire*); of a fine red colour and perfectly transparent. A ruby of good fire and colour is considered of the same value as a diamond of equal size up to two carats; above that weight it is prized higher than diamond on account of the rarity of perfect stones. Cudgegong River, Hunter River, Tumberumba, Mudgee, N.S.W.; in the two last-mentioned localities associated with diamond. *Barklyite*, a variety of magenta colour, at Two-mile Flat, County of Hardinge, N.S.W.; and at Beechworth and Mt. Eliza, Vic.

(*b*) *Sapphire;* blue, bluish white, greenish, often cloudy; sometimes colourless: also bright green (*oriental emerald*). Some varieties exhibit on the basal planes a radiating opalescence in the direction of the lateral axes (*asteriated* or *star sapphire*). Blue sapphire without cloud or flaw commands about half the price of diamond. Stanthorpe, Herberton, Q., in tin-drift.—New England, usually associated with topaz, spinel, and zircon. Blue and green sapphire at Lewell's Ck. near Oberon; small crystals at Severn River, Glen Elgin, Mudgee, N.S.W.—Beechworth, Upper Yarra, Mt. Eliza, Leongatha, Lal Lal, Daylesford, Blackwood, generally in auriferous gravel drift. Star sapphire at Beechworth, Vic.—Macdonnell Range, S.A.—In tin gravels at Ringarooma, Blue Tier, Thomas Plains, Weld River, Table Cape, Tas.

(*c*) *Corundum* (*Adamantine spar*); colour white, bluish, yellowish, grey, brown to black. Lustre dull. Opaque or sub-translucent. Sometimes in large crystals with rough surfaces; more frequently massive. When affected by decomposition changes to *diaspore* (hydrate of alumina). Southport, Q.—Uralla, Bingera, Inverell, Two-mile Flat. In rolled fragments at Cudgegong River. Said to have been observed in olivine basalt at Hill End, Tambaroora, N.S.W. —Beechworth district, Trentham; Cape Otway in large worn pebbles; Leongatha, Vic.

(*d*) *Emery;* crystalline granular, compact, pulverulent.

Usually more or less intermixed with magnetite or hematite. Southport, Q.

120. SPINEL. Isometric; octahedron with edges and solid angles replaced; the faces often curved. Crystals rare, generally in rolled pebbles. Cleavage octahedral.

H 8. G 3·5—4·1. Lustre adamantine to dull. Colour red, blue, green, and yellow of various shades; white, black. Streak white. Transparent to opaque. Fracture conchoidal. Tough.

Comp. Aluminate of magnesia, $MgOAl_2O_3$, with part of the MgO usually replaced by FeO, MnO, and CaO; and part of the Al_2O_3 by Fe_2O_3 and Cr_2O_3. Frequently also contains some silica.

Pyr. BB infusible. Red varieties become brown, green, or colourless by heating, but revert to their original colour on cooling. Not affected by HCl; difficultly soluble in strong H_2SO_4.

Loc. Spinel is found in rocks affected by contact metamorphism, gneiss, mica schist, serpentine, crystalline limestone. Has also been observed in Vesuvian tuffs. Most commonly in waterworn pebbles associated with gold, tin, diamond, sapphire, and other gem-stones. On decomposition is altered to serpentine.

Var. (*a*) *Spinel Ruby*; fine deep red, transparent. In auriferous gravels, Severn River near Uralla; in tin-drift at Tingha, Oban, Bingera, Werong, Bathurst, Macquarie River, Cudgegong River, Inverell. In carboniferous sandstone, Kayon, Richmond River, N.S.W.

(*b*) *Chlorospinel*; grass green, coloured by copper and iron.

(*c*) *Picotite* (*Chrome spinel*); brownish, greenish black, with adamantine lustre. Contains 6 to 8 per cent. of chromium oxide. Usually found in serpentine. Zeehan, Tas.—New Caledonia.

(*d*) *Pleonaste*; black, opaque. Contains sometimes as much as 25 per cent. of iron oxides. Lachlan River in large semi-rounded crystals. Mole Tableland, New England; Muntabilli River, Monaro; Richmond River, Mudgee, N.S.W.—In auriferous drift, Daylesford; Upper Werribee River, in fair-sized octahedra; Blackwood, Upper Yarra, Vic.—Branxholm, Blythe River, Mt. Cameron, Hampshire Hills; in tin-drift at Blue Tier, Tas.—In gold-drift with topaz and zircon in Western Australia.—At Mt. Somma, Naples, Italy, crystals of pleonaste occur embedded in volcanic tufa.

121. CHRYSOBERYL. Rhombic; six-sided prisms terminated by planes of the pyramid or dome; frequently in three penetration twins, and then resembling a truncated hexagonal pyramid. Planes of the prism vertically striated. Cleavage brachydomal perfect; brachypinacoidal imperfect; macropinacoidal indistinct.

H 8·5. G 3·5—3·8. Lustre adamantine. Colour bright green of various shades; greenish white. Transparent to translucent. Some varieties exhibit a bluish opalescence. Fracture uneven to conchoidal.

Comp. Aluminate of glucina, $BeOAl_2O_3$, often with Fe, Ca, Cr, Cu, Pb, Si, or Ti.

Pyr. BB infusible. Difficultly but perfectly dissolved in the micro. salt bead, imparting to it the colour of the metallic oxides present. With cobalt solution turns blue. Not affected by acids.

Loc. In granite, gneiss, and crystalline schists; often in rolled pebbles. Reported from New England, N.S.W., and Woolshed in the Beechworth district, Vic.

122. BEAUXITE (*Bauxite*). Amorphous; in nodular concretions, oolitic, clay-like, earthy.

H 3—5. G 2·55. Colour white, grey, yellow, brown, red. Lustre dull. Opaque.

Comp. Hydrate of alumina and iron, $H_6Al_2O_6$, Fe_2O_3, usually with some silica.

Pyr. BB infusible. Yields much water in the closed tube. With cobalt solution turns blue. With the fluxes reacts for iron. Difficultly soluble in H_2SO_4.

Loc. Originally met with at Beaux in Southern France, where it makes up deposits supposed to be of hydro-thermal origin. Similarly found in other parts of France, in Germany and Ireland. In the United States deposits of beauxite extend from Adairsville in Georgia south-westward for a distance of sixty miles to the neighbourhood of Jacksonville in Alabama, invariably, it appears, in connection with fault fissures. The mineral, occurring in nodules with concentric structure, is embedded in a clayey matrix of similar composition, the whole occupying lenticular masses upwards of fifty feet in thickness. These deposits rest on limestone, which in its turn reposes on pyritous clay slate. The latter is liable by oxidation to be changed into sulphate of alumina and alum, solutions of which, rising in the fault fissures and meeting with the limestone, would lead to the production of gypsum and hydrate of alumina. The latter, held in suspension by the ascending waters, would be carried to the surface, where in the process of desiccation it would assume a concretionary structure. Beauxite is of considerable economic importance from the circumstance that it is the "ore" now chiefly used in the manufacture of aluminium. Although it is not at present known to exist in Australia, the necessary conditions for its occurrence, as above explained, are by no means unusual, and the possibility of its being discovered in deposits of workable extent is therefore not altogether excluded.

METALLIC MINERALS.

THE system here adopted in regard to the grouping of the oxides and salts of each metal has been explained on p. 125.

GOLD GROUP.

123. **NATIVE GOLD.** Isometric; octahedron, rhombic dodecahedron, cube, and combinations of these forms. Crystals often distorted. Commonly in mossiform and filiform aggregates; spongy, reticulated; in irregular grains, shreds, and scales, and in rolled fragments.

H 2·5—3. G 19·3 when pure, to 15·5 when containing much silver or copper. Lustre metallic. Colour and streak golden yellow when pure, reddish yellow, pale yellow to silvery white when alloyed with silver or copper. Malleable and ductile.

Comp. Au; as a rule contains silver, copper, iron, palladium, etc., in variable proportions. The fineness of native gold in the principal mining fields is indicated in the following table—

	Au.	Ag.	Cu & Fe.
Tasmania and Victoria	96	3·5	0·5
New South Wales and Western Australia	93·5	6	0·5
Queensland	87·2	12	0·8
Gympie, Q.	85	14	1
Mt. Morgan, Q.	99·75	—	0·25
Otago, N.Z.	94	5·5	0·5
Nelson, N.Z.	86—90	10—14	—
Thames, N.Z.	70	30	—
California	87—89	11—13	—
Canada	85—90	10—15	—
South Africa	84—92	8—16	—
Ural and Siberia	89—96	4—10	0·5—1

Pyr. F 2·5—3. Not affected by fluxes. Insoluble in HCl or HNO_3. Completely soluble in aqua regia.

Loc. Gold is generally associated with quartz; indeed so intimate are the paragenetic relations of the two minerals that quartz is often spoken of as the "matrix" of gold, although it is by no means the only host of native gold. The miner distinguishes between *lode gold* (reef gold) and *alluvial gold* (placer gold). The former is obtained from veins, zones of impregnation, and other primary forms of deposit; the latter has found a lodgment in the detritus derived from the veins, etc., and occurs scattered among recent sands and gravels in the shape of minute scales ("fine gold"), flattened or rounded grains ("shotty gold"), or larger masses ("nuggets"). The table on next page gives a list of some of the largest nuggets found in Victoria.

Lode gold is either disseminated in visible, though sometimes microscopic, grains through the gangue ("free-milling ore"), or it is invisibly diffused through sulphides of other metals ("gold ore" proper). Free gold, though chiefly found in quartz, also occurs in calcite, limestone, gypsum, ankerite, barite, hornblende, augite, schorl, magnetite, micaceous iron, limonite, manganese ore, and serpentine; and in rocks of which these minerals form constituents, such as diorite, andesite, trachyte, propylite, felsite, granite, gneiss; not rarely also in the slate, sandstone, and phyllite casings of quartz veins. As an ore it affects pyrite, marcasite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, stibnite, bismuthinite, tetradymite, and fahlore. Decomposition of these minerals (if originally auriferous) invariably leads to the liberation of the gold, hence the frequent association of native gold with limonite, scorodite, native copper, chrysocolla, cervantite, bismutite, bismite, etc. Galena, though commonly associated, and often in close contact, with native gold (and on that account viewed by the miner with favour as a "likely" mineral), is not known to be auriferous *per se.* The common assumption that the gold in these ores is in the metallic condition is by no means well founded. The ease and rapidity with which the gold disengages itself from the

Name.	Locality.	Depth below surface in feet.	Date of discovery.	Weight.	
				oz.	dwt.
"The Welcome"	Bakery Hill, Ballarat	180	June 11, 1858	2195	0
"The Viscountess Canterbury"	Rheola	7	Oct. 3, 1870	884	10
"The Beauty"	Robinson Crusoe Gully, Bendigo	20	March 1861	377	6
"The Needful"	Rheola	4		246	16
"Kum Tow"	Rheola	5		718	0
	Kiddy's Lead, Buninyong	36	July 15, 1878	250	14
"The Crescent"	Rheola	2	April 2, 1872	176	8
	Broomfields Gully, Creswick	100	Aug. 12, 1872	46	15
	Red Streak Lead, Creswick	180	Aug. 31, 1872	30	1
	White Horse Range, Ballarat	14	Dec. 25, 1875	410	8
"The Precious"	Rheola	12	Jan. 5, 1871	1621	2
"The Viscount Canterbury"	Rheola	15	May 31, 1870	1105	0
"The Schlemm"	Dunolly	3	July 11, 1872	478	0
	Kangaroo Gully, Bendigo	9	1856	242	17
"The Little Highlander"	Corindhap, south of Ballarat	30	July 18, 1878	187	5
	Browns, Scarsdale	150	April 8, 1880	75	12
"The Christmas Gift"	Break o' Day, Rokewood	29	Dec. 12, 1877	175	0
	Key Mine, Creswick	205	Jan. 1871	32	0
	Durham Lead, Ballarat	160	June 21, 1875	60	0
"The Lady Loch"	Midas Mine, Sulky Gully, Ballarat	118	Aug. 3, 1887	617	0
	Black Hill, Ballarat East	400	Feb. 15, 1876	122	0
	Rising Sun Mine, Ballarat East	300	1880	46	2
	Woah Harop Canton Mine, Ballarat East	494	Oct. 1890	137	0
	Old Quartz Hill, Castlemaine	40	1858	156	0

NOTE.—The three last-mentioned nuggets were found in quartz, at the junction of the veins and a pyritous seam ("indicator").

slag in the ordinary assaying process renders it difficult to believe that the particles of gold are in such a minute state of subdivision as must exist in the case of a mechanical mixture. The difficulty of the question is enhanced by the doubt whether the gold is present as a sulphide simply, or as a combination (not a mere mixture) of sulphide of gold and another metallic sulphide.

The rocks which have either directly or through their associated veins proved auriferous in different parts of the world vary so widely as to age and origin as to justify the statement that the geological range of gold is exceeded by that of no other metal, iron excepted. The application will be seen from the undermentioned examples of the occurrence of gold.

Archæan: In kaolinized gneiss, Quartz Hill, Denver, Colorado; in gneissoid sandstone, San Bernardino, California.

Cambrian (normal and altered): South Dakota, U.S.A.; Western Australia (?); South Australia (?).

Lower Silurian (normal and altered): Central and Western Victoria, Tasmania, South Australia, Western Australia (?), Peake Downs, Q. (?); Wales, Ireland, Sweden, Ural, Siberia, India, South Africa (?).

Upper Silurian: Eastern Victoria, New South Wales, Queensland; Hite's Cove, west of Mariposa, California.

Devonian: Queensland, New South Wales, Gippsland, Vic.; South Africa (?).

Carboniferous: Copeland, N.S.W.; Utah, U.S.A.

Permo-Carboniferous: Gympie, Rockhampton, Q.

Triassic: Hawkesbury sandstone, N.S.W. Gold-bearing coal at Witwatersrand, South Africa.

Jurassic: In conglomerate, Gippsland, Vic.; Mariposa, California.

Cretaceous: Croydon, Q.; east of Mariposa, California.

Eocene: Washington district, Nevada, U.S.A.; Transylvania.

Miocene: Deep leads, Gippsland, Elaine, Morrisons, Vic. In propylite, Tokatea, Thames, N.Z.; Schemnitz, Hungary.

Pliocene: Marine and fluvial drifts, Victoria, South Australia, New South Wales; California.

Quaternary: Detrital deposits, Australia, New Zealand, California, Africa, India, Ural, Siberia.

Granite: Charters Towers, Ravenswood, Etheridge, Croydon, Q.; Tambaroora, N.S.W.; Beechworth, Great Western, Vic.; Calavaras, Mono, Riverside, Grass Valley, California.

Felsite: Pambula, N.S.W.; San Bernardino, Cal.

Serpentine: Gundagai, N.S.W.; New Caledonia; Coulterville, Cal.

Diabase: Pinehill, Cal., in barite veins in kaolinized diabase; Nevada, U.S.A.; Mt. Morgan, Q. (?).

Diorite: Gippsland, Vic.; New South Wales, Queensland, Western Australia, Scandinavia, Tuolumne, Cal.

Porphyrite: Black Snake, Kilkivan; Mt. Leyshon, Q.; California.

Rhyolite: Arizona, South Dakota; Benito, Cal. U.S.A.

Varied as the geological conditions are under which gold is met with in different places, it seems probable that metallic gold has been in most instances produced by the action of hydrogen sulphide, or sulphate of iron, or organic matter on solutions of auric chloride. In the case of auriferous sulphides it may, as already pointed out, exist in the condition of a sulphide. As an alternative, it has been suggested that the metal may have been originally in the state of a silicate; diffused through a magma of colloid silica which was being subjected to intense heat and pressure. The silicate of gold may be such an unstable compound that as soon as the magma cooled and solidified into quartz the gold was set free. We know from observation that silica deposited from heated water is always in an hydrated condition, and it may be inferred that the crystalline and anhydrous state is superinduced by pressure in depth.

Var. (*a*) *Electrum*, a native alloy of gold and silver, the latter varying in amount from 20 to 36 per cent. Colour amber yellow (whence the name), pale yellow to yellowish white. Omeo, Vic.—Thames, N.Z.—Transylvania.—Peru.—Virginia, U.S.A.

(*b*) *Bismuth Gold* (*Maldonite*), a native alloy of gold and bismuth; maldonite contains 35 per cent. of bismuth. Maldon, Vic.—Biggenden, Q.—Alaska, U.S.A.

(*c*) *Palladium Gold* and *Rhodium Gold*, contain 10 per cent. of palladium and 34 to 43 per cent. of rhodium respectively. Brazil.

124. SYLVANITE. Monoclinic; octahedra, often twinned, also granular massive. Cleavage clinodiagonal distinct.

H 1·5—2. G 7·9—8·3. Lustre metallic. Colour steel grey to silver white, tarnishes yellow. Streak same as colour.

Comp. Telluride of gold and silver, (Au, Ag)Te_2, usually with a little antimony and lead. When pure contains—Gold 24, Silver 13, Tellurium 63.

Pyr. F 1, colouring the flame bluish green. On charcoal gives a white sublimate, and after continued heating a metallic bead. Decomposed by warm concentrated H_2SO_4, with separation of a grey precipitate of tellurium and colouring the solution purple; this colour fades or entirely disappears on addition of water. Soluble in aqua regia, leaving a precipitate of chloride of silver.

Loc. Transylvania.—Calavaras, California.

Var. *Petzite.* H 2·5. G 8·8. Colour and streak grey to black. Brittle. *Comp.* AuTe + 3 AgTe; Gold 25, Silver 42, Tellurium 33. In other varieties part of the gold is still further replaced by silver, and by degrees the mineral passes into *Hessite*, AgTe, which contains 62 per cent. of silver with no, or but traces of, gold.

125. NAGYAGITE. Tetragonal; eight-sided tabular crystals; foliated, granular. Cleavage basal.

H 1—1·5. G 6·9—7·2. Lustre splendent, metallic. Colour and streak lead grey to black. Sectile. In thin plates flexible.

Comp. Sulpho-telluride of gold and lead, $Au_2Pb_{14}Te_7S_{17}$, or Gold 9, Lead 51, Tellurium 32, Sulphur 8; usually with some antimony or copper.

Pyr. Like sylvanite, but gives no silver reactions. In the aqua regia solution $H\,SO_4$ gives a white precipitate of sulphate of lead.

Loc. Nagyag and other places in Transylvania.

SILVER GROUP.

The minerals of this group are easily fusible, and in the presence of lead, bismuth, or antimony give a carmine red coating on charcoal. To eliminate the silver from these minerals (as well as from argentiferous sulphides of other metals) they are heated in the following manner. One part of the powdered assay is mixed with an equal part of borax glass and five parts of test lead (or less, if the mineral already contain lead). The charge is placed in a deep cylindrical cavity in charcoal and exposed to a strong reducing blast for about five minutes, to be followed by a moderate oxidizing blast. The resulting button is an alloy of silver and lead. Remove from the coal and separate the slag between the hammer and anvil. Next prepare in a fresh piece of charcoal a dish-shaped cavity half-an-inch in diameter and one-eighth of an inch in depth, and line it with moistened bone ash, which is pressed into it with the agate pestle. Into this cupel (which is first thoroughly dried in the blowpipe flame) the button is placed, and the scorification conducted first in a strong, afterwards in a moderate, oxidizing blast until the whole of the lead is volatilized. The remaining bead represents the quantity of silver originally in the assay.

126. NATIVE SILVER. Isometric; octahedron, cube, dodecahedron, and combinations of these forms. Crystals

generally distorted. Usually filiform, arborescent, reticulated; also in irregular grains, plates, and in thin films.

H 2·5—3. G 10·5. Lustre metallic. Colour and streak silver white; tarnishes black on exposure. Malleable, ductile.

Comp. Ag. Usually with some copper or gold.

Pyr. F 2—2·5. Soluble in HNO_3. In the nitric solution HCl gives a white precipitate of chloride of silver, which turns reddish grey when exposed to the light.

Loc. Occurs in veins traversing gneiss and foliated schists. Often results from the alteration of other argentiferous minerals, especially in the gossan part of lodes. Mount Albion, Q.—Broken Hill and other mines, Barrier Range. Some large masses, weighing several hundredweights, were raised from the Australian Broken Hill Mine in the year 1892.—White Rock, Fairfield, in felsite; Sunny Corner, N.S.W.—St. Arnaud, Vic., in quartz.—Dundas, Whyte River, Penguin, Tas.; in stanniferous granite with native bismuth and fluorite at Blue Tier, North-eastern Tasmania. The largest masses of native silver have been obtained in Peru, Mexico, and Kongsberg in Norway.

127. ARGENTITE (*Silver Glance*). Isometric; cube, octahedron, rhombic dodecahedron, and their combinations. Also arboriform, filiform, reticulated, and massive.

H 2—2·5. G 7·2. Lustre metallic. Colour grey to greyish black. Streak dark grey, shining. Fracture uneven. Sectile.

Comp. Silver sulphide, Ag_2S. Silver 87·1, Sulphur 12·9, sometimes with traces of lead, copper, and iron.

Pyr. F 1·5. In open tube evolves SO_2. On charcoal in OF is reduced to the metallic state.

Loc. Occurs in mineral veins with other silver and lead ores. Silverfield, Tinaroo, Q.—Peelwood, Gulgong, Sunny Corner; Boorook, north-east of Tenterfield; Macleay district in silver-lead veins traversing granite and Devonian slates; Umberumberka, N.S.W.—Morse's Creek, Ovens, Vic., in quartz.—Mount Lyell, Whyte River, Tas.—Collingwood, Nelson, N.Z. The high percentage of silver contained in the lead ore of some districts, *e.g.* Ravenswood, Q.; Umberumberka, N.S.W.; Flora Dell, Northern Territory, Whyte River, and elsewhere in Western Tasmania, is perhaps in a measure due to the presence of minute grains of argentite disseminated in the isormorphous galena.

128. **STROMEYERITE** (*Silver-copper Glance*). Rhombic; brachypinacoids terminating in domes or octahedra; often in penetration twins. Also granular massive.

H 2·5—3. G 6·2. Lustre metallic. Colour dark grey. Streak shining. Fracture sub-conchoidal.

Comp. Sulphide of silver and copper, $(Ag_2, Cu_2)S$. Silver 53·1, Copper 31·1, Sulphur 15·8; usually contains some iron.

Pyr. F 1. Moistened with HCl imparts an azure blue colour to the blowpipe flame. Yields SO_2 in the open tube. On charcoal in OF fuses to a metallic globule, from which the silver may be eliminated by cupelling. With the fluxes reacts for copper. In the nitric solution HCl produces a precipitate of chloride of silver; neutralized by NH_3 the solution becomes blue.

Loc. Generally occurs in association with copper pyrites and galena. Umberumberka, Australian Broken Hill and other mines, Barrier Range.—Mount Lyell, Tas.

129. **DYSCRASITE.** Rhombic; six-sided prism, often twinned. Generally granular and loose aggregates. Cleavage basal perfect, brachydiagonal distinct.

H 3·5—4. G 9·5. Lustre metallic. Colour and streak tin-white; on exposure tarnishing yellow or grey. Fracture uneven.

Comp. Silver antimonide, Ag_2Sb. Silver 78, Antimony 22. Sometimes approaching Ag_3S_2 with 73 per cent. of silver.

Pyr. F 1·5. In open tube and on charcoal emits dense white fumes of SbO_3. After prolonged heating the whole of the antimony is volatilized, and there remains a globule of silver. The reduction is expedited by using a mixed flux of soda and borax.

Loc. With other silver ores in the Australian Broken Hill Mine, Barrier Range, N.S.W. Several masses, the largest weighing 2300 lbs. and 1600 lbs. respectively, were obtained at this mine.

130. FREIESLEBENITE. Monoclinic; orthopinacoids surmounted by domes. Faces of the prism longitudinally striated. Perfect prismatic cleavage.

H 2—2·5. G 6—6·4. Lustre metallic. Colour and streak light grey. Fracture sub-conchoidal. Brittle.

Comp. Sulphantimonide of silver and lead, $5\,(Ag_2, Pb)S + 2\,Sb_2S_3$. Silver 24·3, Lead 31·2, Antimony 25·9, Sulphur 18·6. Often with traces of copper and iron.

Pyr. F 1. On charcoal gives a yellow coating. In the nitric solution H_2SO_4 gives a precipitate of sulphate of lead. Otherwise like dyscrasite.

Loc. With other silver ores at the Australian Broken Hill Co.'s mine, and at Umberumberka, Barrier Range.

131. PYRARGYRITE (*Dark red silver ore*). Hexagonal; primary form six-sided prism terminating in three or six planes of the rhombohedron; often twinned. Also granular, massive, and powdery. Cleavage rhombohedral distinct.

H 2—2·5. G 5·8. Lustre metallic to adamantine. Colour black to carmine red. Streak carmine red. Translucent to opaque. Fracture conchoidal.

Comp. Sulphantimonide of silver, $3\,Ag_2S + Sb_2S_3$. Silver 59·8, Antimony 22·5, Sulphur 17·7. Part of the antimony sometimes replaced by arsenic, and so passing into proustite.

Pyr. F 1. On charcoal deposits a white sublimate of antimony oxide. With soda reduced to metallic silver, with the formation of an hepar.

Loc. Usually associated with calcite, galena, and native [illegible] Occurs sparingly at Broken Hill.—Abundant in silver lodes, Mexico, Chili.—Also at Freiberg and Harz (Germany). [illegible] to change into argentite.

132. PROUSTITE (*Light red silver ore*). Hexagonal: rhombohedral. Commonly granular massive.

H 2—2·5. G 5·5. Lustre adamantine. Colour carmine red. Streak carmine to scarlet red. Translucent. Fracture conchoidal.

Comp. Sulpharsenide of silver, $3\ Ag_2S + As_2S_3$. Silver 65·4, Arsenic 15·2, Sulphur 19·4. Part of the arsenic sometimes replaced by antimony, approaching pyrargyrite.

Pyr. F 1. In the open tube and on charcoal emits arsenical vapours. With soda reduced to metallic silver with formation of an hepar.

Loc. Occurs often in association with pyrargyrite. Rare at Broken Hill, N.S.W. Used to be a rather common silver ore in Freiberg mines.

133. STEPHANITE. Rhombic; six-sided prisms terminating in truncated pyramids; crystals of the aragonite type common. Also granular massive. Cleavage brachydiagonal and brachydomal imperfect.

H 2—2·5. G 6·26. Lustre metallic. Colour and streak iron black. Fracture uneven. Brittle.

Comp. Sulphantimonide of silver, $5\ Ag_2S + Sb_2S_3$. Silver 68·5, Antimony 15·3, Sulphur 16·2. Frequently contains arsenic, iron, and copper.

Pyr. F 1. Gives reactions for sulphur and antimony. Fused with a mixture of borax and soda on charcoal yields a bead of metallic silver.

Loc. Occurs in silver lodes with other argentiferous minerals. Abundant in the Comstock Lode, Nevada, U.S.A.; Mexico; Saxony.—Umberumberka, Barrier Range, in a pulverulent form with polybasite, native silver, siderite, and cerussite. Reported from the Owen Meredith and Scamander silver-mines, Tas.

Through loss of Sb_2S_3 stephanite is converted into argentite; this on further loss of sulphur becomes native silver, which is commonly associated with stephanite.

134. POLYBASITE. Rhombic; tabular six-sided prisms, the basal planes of which usually striated parallel to alternate edges. Also granular massive. Cleavage basal distinct.

H 2—3. G 6·21. Lustre metallic. Colour and streak iron black. Opaque. In thin splinters cherry red and translucent. Fracture uneven. Brittle.

Comp. Sulpharseno-antimonide of silver and copper, $9(Ag_2, Cu_2)S + (Sb, As)_2S_3$. Silver 65·5, Copper 6·7, Antimony 5·8, Arsenic 3·9, Sulphur 18·1. The percentage of copper varies; often contains iron and zinc.

Pyr. F 1. Moistened with HCl colours the flame azure blue. In the open tube yields dense antimony fumes. On charcoal emits garlic odour. With soda forms an hepar. After prolonged heating in OF on charcoal gives a metallic globule, from which the silver may be eliminated by cupellation.

Loc. In veins with other silver ores. Often altered into stephanite. A common ore in the silver lodes of Mexico, Chili, Freiberg, and Bohemia. Occasionally met with at Umberumberka, Barrier Range, with stephanite in siderite.

135. CERARGYRITE (*Hornsilver*). Isometric; cubes, octahedra, twinned octahedra. Also massive, botryoidal, encrusting, stalactitic.

H 1. G 5·4. Lustre resinous to pearly. Colour greyish green, brown on exposure. Streak shining. Translucent. Fracture uneven to earthy. Sectile like wax, or horn.

Comp. Silver chloride, AgCl. Silver 75·3, Chlorine 24·7. Amorphous varieties often contain oxide of iron and clayey matter.

Pyr. F 1. When taken up in a micro. salt bead which has been previously charged with oxide of copper, colours the flame azure blue (CuCl). In the closed tube fuses, but is not reduced. Heated with potassium bisulphate in the closed tube fuses to a bead which is hyacinth red to orange yellow while hot, and pale sulphur yellow when cold. With soda on charcoal yields a globule of silver. Soluble in NH_3. Placed on a strip of metallic zinc, moistened with a drop of water, is reduced to the metallic state.

Loc. Occurs generally in the gossan part of silver veins, investing other minerals, or disseminated in the clay derived from the decomposition of the vein gangue. Mt. Albion, Herberton, Ravenswood, Q.—Common in the silver veins of the Barrier Range; in minute but well-formed crystals at the Pinnacles; in large masses (slugs), sometimes of several hundredweights, in the neighbourhood of Silverton; in kaolinitic clay at Broken Hill, where it is found from the surface down to a depth of 400 feet. Boorook, north-east of Tenterfield, N.S.W.—St. Arnaud, Vic.—Ediacara, S.A.—Zeehan, Dundas, Whyte River, Tas.

136. **EMBOLITE.** Isometric; like cerargyrite.

H 1. G 5·4. Lustre resinous to adamantine. Colour greyish green to bright yellowish green, darkening on exposure. Sectile, wax-like.

Comp. Chloro-bromide of silver, Ag(Cl, Br). Ag 61—72, Cl 5—20, Br 8—33; the greyish-green variety contains most chlorine, the yellowish and deep green most bromine.

Pyr. F 1. Heated with potassium bisulphate in closed tube emits brown vapours of bromine, and fuses to a hyacinth red pearl, which on cooling turns yellow. With soda on charcoal reduced to the metallic state.

Loc. Occurs in association with cerargyrite in the localities mentioned under that mineral.

137. **BROMYRITE.** Isometric; like cerargyrite.

H 2·5. G 5·9. Lustre adamantine. Colour amber yellow, greenish yellow, superficially tarnishing to green on exposure. Sectile.

Comp. Bromide of silver, AgBr. Silver 57·4, Bromine 42·6.

Pyr. F 1. On charcoal yields a globule of silver. Heated in the closed tube with potassium bisulphate emits brown vapours of bromine. Fused with a mixture of sulphur and bismuth on charcoal produces a deep yellow sublimate. Difficultly soluble in NH_3. On moistened zinc is reduced to the metallic state.

Loc. Like cerargyrite.

138. IODYRITE. Hexagonal; in hexagonal plates and scales. Also massive, disseminated, and encrusting. Cleavage basal perfect.

H 1 and under. G 5·6. Lustre resinous. Colour sulphur to citron yellow when pure; greenish yellow when containing bromine or chlorine; brownish on exposure. Streak citron yellow. Translucent. Flexible in thin scales. Sectile.

Comp. Iodide of silver, AgI. Silver 46, Iodine 54; sometimes with chlorine or bromine.

Pyr. F 1. On charcoal and on moistened zinc reduced to the metallic state. Heated with potassium bisulphate in the closed tube emits violet fumes of iodine, and fuses to a bead which is brownish black while hot, turning garnet red on cooling, and finally becomes citron yellow when cold. Fused with sulphur-bismuth on charcoal produces a scarlet red sublimate.

Loc. Occurs with other haloids in the gossan of silver lodes in the Broken Hill and other mines in the Barrier Range, N.S.W.

COPPER GROUP.

The minerals of this group are, with the exception of the oxide and silicate, easily fusible at from 1 to 3 to metallic globules. They impart an emerald-green colour to the blowpipe flame; when moistened with hydrochloric acid (or better, on the addition of a grain of chloride of sodium) the flame is momentarily coloured a brilliant azure blue. Fused with borax or microcosmic salt in the oxidizing flame they colour the glass green while hot and blue when cold. In the reducing flame the borax bead is colourless while hot and opaque red when cold. The last-mentioned very characteristic reaction is more readily obtained by adding to the bead a grain of tin chloride and fusing in the oxidizing flame on platinum wire. (Fusion with metallic tin on charcoal has the same effect, but is less convenient.) They are more or less easily soluble in nitric acid; the greenish solution when neutralized by ammonia becomes fine azure blue.

139. NATIVE COPPER. Isometric; mostly octahedral, generally distorted. Also arboriform, filiform, and granular massive.

H 2·5—3. G 8·85. Lustre metallic. Colour copper red, tarnishing brown on exposure. Streak shining, red. Malleable, ductile. Fracture hackly.

Comp. Metallic copper, Cu, frequently with a small proportion of silver.

Pyr. F 3. Fused on charcoal solidifies under a coating of black oxide. For other reactions, see *ante.*

Loc. Occurs in veins and bedded deposits of diverse geological ages, particularly in the neighbourhood of eruptive rocks. In its primary mode of occurrence it is disseminated through quartz and other massive rocks; in a secondary form of deposit it is a derivative of sulphides and other copper ores; lastly, it occurs as rolled fragments in modern detrital deposits. Accordingly it is met with at the greatest depth which the miner has reached (4500 feet, Tamarack copper-mine, Lake Superior), while at the same time it is found in the gossan of veins, and even in detached masses embedded in the surface soil (Siberia). In Massachusetts, Connecticut, and New Jersey, U.S.A., native copper occurs in layers one-tenth of an inch thick in Triassic or Jurassic sandstone, sometimes forming sheets several hundred square yards in extent. Similar masses of sheet copper have been observed in serpentine at Nelson, N.Z., and on a smaller scale in decomposed greenstone dykes traversing stanniferous felsite porphyry at Mt. Bischoff, Tas.

At Lake Superior, U.S.A., forms veins and bunches in red melaphyre, and great masses of pure copper are often encountered at the boundary of the eruptive rock and sandstone. One such single block measured 45 feet in length, 22 feet in width, and 8 feet in thickness, and weighed 420 tons. The largest masses of native copper in Australia have been obtained in Queensland, especially in the Cloncurry, Peake Downs (Clermont), Keelbottom (Townsville), Rockhampton, and Mt. Perry copper-mines. With native gold at Morinish, Rockhampton; with tin ore, Argyle Mine, Herberton, Q.—Finely crystallized and arborescent, Broken Hill, Barrier Range; Carcoar, Bathurst, Cobar, Canoblas, Peelwood, Parkes, N.S.W.—In auriferous quartz veins, Specimen Gully Reef near Castlemaine, Armagh Reef, Creswick, Wilson Reef, St. Arnaud. In rolled fragments in gold-drift at the Park Lead, Ballarat; Lewers Lead, Creswick; Thompson River, Gippsland, Lothair Mine, Clunes, Vic.—Moonta, Wallaroo, Angaston, Sliding Rock, Boolcoomata, S.A.—Pine Creek, Daly River, Eveleen, Northern Territory.—Mt. Lyell, Macquarie Harbour, Mt. Bischoff, Hampshire Hills, Wilmot River, Tas.—Northampton, Roebourne, W.A.—Aniseed Valley, Dun Mountain, Champion Mine, D'Urville Island, Nelson; Moke Creek, Otago, N.Z.—Eastern part of New Caledonia.

140. CHALCOCITE (*Copper Glance*). Rhombic; six-sided prisms and domes. Penetration twins common; isomorphous with stromeyerite. Cleavage prismatic perfect. Also granular, compact, or powdery.

H 2·5—3. G 5·5—5·8. Lustre metallic. Colour and streak blackish grey; tarnishes green or blue. Fracture conchoidal. Sectile.

Comp. Copper protosulphide, Cu_2S. Copper 79·8, Sulphur 20·2. Frequently with traces of iron or silver.

Pyr. F 1. On charcoal with soda forms an hepar, and is reduced to the metallic state. In the closed tube gives no sublimate of sulphur.

Loc. Occurs in veins with copper pyrites, also disseminated in quartz with native gold. Morinish, near Rockhampton, Q., in auriferous quartz veins.—In macled crystals Mt. Hope. Massive at Nymagee, Cobar, Parker, Peelwood, Bathurst, Icely, Carcoar. Argentiferous at Barrier Range, Severn River, Tenterfield, Wyndham, Capertree, Ophir, N.S.W.—In auriferous quartz veins, Steiglitz. With chalcopyrite at Thompson River copper-mine, Walhalla, Vic.—Moonta, S.A.—Reported from Mt. Maurice, Mt. Ramsay, and Badger Head, Tas.—Northampton; Gilian Mine, Victoria district; Roebourne, W.A.—Aniseed Valley, and D'Urville Island, Nelson, N.Z.—New Caledonia.

On decomposition chalcocite yields covellite, melaconite and chalcopyrite, with which minerals it is frequently associated.

141. COVELLITE (*Indigo Copper*). Hexagonal; pyramidal. Crystals rare; usually massive, globular, earthy. Cleavage basal distinct.

H 1·5—2. G 4·6. Lustre of crystals sub-metallic to resinous, of massive varieties dull. Colour indigo blue to bluish black. Streak shining, grey or black. Opaque.

Comp. Copper monosulphide, CuS. Copper 66·5, Sulphur 33·5. Frequently with some iron.

Pyr. F 2. Reduced with soda on charcoal. In the closed tube gives a sublimate of sulphur.

Loc. Occurs with azurite and cerussite in the upper parts of the Broken Hill silver lode, Barrier Range, N.S.W.—In auriferous quartz veins, Steiglitz, Dunolly, Specimen Gully near Castlemaine, Glen Dhu Reef near Landsborough, Crooked River, Vic.—Abundantly at Moonta and Wallaroo copper-mines; Kapunda, S.A.—In the Victoria district, Irwin River, Whim Well, Kimberley, Mt. Barren, W.A.

142. CHALCOPYRITE (*Copper Pyrites*, *Yellow Copper ore*). Tetragonal, octahedron with edges and solid angles usually replaced; tetrahedron with replaced solid angles; often macled. Commonly massive, granular, powdery. Cleavage prismatic imperfect.

H 4. G 4·1—4·3. Lustre metallic. Colour brass yellow; on exposure, particularly in moist situations, tarnishes to golden yellow, and often with a brilliant iridescence (peacock ore). Streak greenish black. Fracture uneven. Brittle.

Comp. Sulphide of copper and iron, (Cu, Fe)S. Copper 34·6, Iron 30·5, Sulphur 34·9. In the "yellow copper ore" of the miner, which is in the main a mixture of chalcopyrite and pyrite, the percentage of copper varies indefinitely. When it sinks to below 5 per cent. the material is no longer regarded as a copper ore, and is properly described as a cupriferous iron pyrites. The colour of the ore becomes paler as the amount of iron increases. Copper pyrites is often auriferous, and in some localities constitutes a valuable gold ore.

Pyr. F 2. On charcoal fuses to an iron-grey magnetic globule. With soda forms an hepar.

Loc. Copper pyrites constitutes the commonest ore in copper-producing districts, and often accompanies ores of lead, silver, and gold, either forming veins *per se*, or disseminated in quartz, greenstone, and other vein gangue. In the gossan of lodes it is generally altered to limonite and sulphate of copper, and leads to the production of silicate, oxides, and carbonates of copper; at greater depth it is often changed to covellite. It frequently accompanies pyrite, sphalerite, and galena in gold-bearing quartz veins, and is then usually itself auriferous. Crystallized at Nebo and Clermont. With silver lead and zinc ores at Tinaroo. Auriferous at Mt. Perry, Ravenswood, and Charters Towers, Q.—Cobar and Nymagee copper-mines. Commonly associated with lead, silver, and zinc ores in the silver lodes of the Barrier Ranges. Auriferous in quartz veins on most of the gold-fields of New South Wales and Victoria.—St. Arnaud, Maldon, and Bethanga in massive veins, highly auriferous.—Moonta, Wallaroo, Blinman, Burra Burra, Yudanamutana, Kapunda, Mt. Lyndhurst, S.A.—Mt. Lyell, Mt. Ramsay, Mt. Heemskirk, Mt. Bischoff, Penguin, Mt.

Claude, Bell Mount, Tas.—Northampton and Roebourne districts, W.A.—Champion Mine, Nelson; Waipori, Moke Creek, Dusky Sound, Otago; Golden Crown, Thames, N.Z.

143. Bornite (*Erubescite*). Isometric; combinations of the cube, octahedron, and dodecahedron; macled octahedra. Commonly granular and compact. Cleavage octahedral indistinct.

H 3. G 5. Lustre metallic. Colour reddish bronze brown, tarnishing purple (*horseflesh ore*), and iridescent (*variegated copper ore*). Streak lead grey. Fracture uneven. Brittle.

Comp. Copper and iron sulphide, $Cu_2S + CuS + FeS$. Copper 60—71, Iron 7—18, Sulphur 21—28, very variable, being generally mixed with chalcopyrite, or pyrite, or both.

Pyr. Like chalcopyrite, but more easily fusible.

Loc. Being readily liable to oxidation is rarely found in veins near the surface. Cloncurry, Mt. Perry, Blackall, Q.—Carcoar, Bingera, Cow Flat, Bathurst; Louisa Creek, County of Wellington, N.S.W.—Thompson River copper-mine, near Walhalla, Vic.—Moonta, Barossa, Kapunda, Peake Ranges, Mingary, S.A.—In stanniferous granite, Blue Tier, Eastern Tasmania.

144. Tetrahedrite (*Fahl ore*). Isometric; tetrahedra, often in penetration twins. Also granular, cryptocrystalline, or compact.

H 3—4. G 4·5—5·1. Lustre metallic. Colour light steel grey to black. Streak grey to reddish. Translucent to opaque. Fracture uneven. Brittle.

Comp. Sulphantimonide of copper, $4\ CuS + Sb_2S_3$, with part of the copper replaced by silver (invariably), iron, zinc, and mercury, and part of the antimony by arsenic or bismuth, giving approximately $4\ [(Cu, Ag)_2S, (Fe, Zn, Hg)S + (Sb, As, Bi)_2S_3$. Copper 30—42, Silver 1—31, Iron 1—9, Zinc 0—7, Mercury 0—16, Antimony 12—33, Arsenic 0—20, Bismuth 0—1·5, Sulphur 20—30. Sometimes also traces of cobalt and nickel.

Pyr. F 1·5. After prolonged roasting, yields with soda on charcoal a metallic globule which is an alloy of copper and silver chiefly. The latter metal may be eliminated by cupellation. In the open tube produces dense white fumes of antimony oxide. The presence of other metals may be determined by the tests described under their respective heads.

Loc. Occurs in veins and impregnations with other copper and silver ores. Great Extended silver-mine, Ravenswood, containing from 7 to 15 per cent. of silver; Mt. Orange copper-mine, Nebo; Cloncurry, Q.—Australian Broken Hill Mine, Barrier Range. Vegetable Creek, Wiseman's Creek, Tenterfield; Ten-mile Creek and Pye's Creek, County of Clive, N.S.W.—Associated with pyrite, chalcopyrite, sphalerite, calcite, brownspar, and siderite in quartz, in the 1200 feet level of the Band and Albion Mine, Ballarat. In auriferous quartz, Albion Reef, Steiglitz.—Ediacara silver-mine, west of Beltana, S.A.—Zeehan, Dundas, Mt. Lyell, Penguin, Tas.—Thames gold-field; Richmond Hill, Nelson, N.Z.

145. BOURNONITE. Rhombic; stout four and six-sided prisms terminating in domes; often twinned, four individuals crossing under right angles, somewhat resembling a cog-wheel (whence the miners' term, "wheel ore"). Also granular and compact. Cleavage brachydiagonal imperfect.

H 3. G 5·8. Lustre metallic. Colour and streak grey to black. Opaque. Fracture uneven. Brittle.

Comp. Sulphantimonide of copper and lead, $(Cu_2S + 2\,PbS) + Sb_2S_3$. Copper 12·9, Lead 42·4, Antimony 25, Sulphur 19·7. Usually with traces of iron and manganese.

Pyr. F 1. After prolonged roasting on charcoal yields a globule of copper. In open tube gives antimony fumes; on charcoal a yellow sublimate. In the nitric solution H_2SO_4 produces a white precipitate of lead sulphate.

Loc. Associated with other ores of lead, copper, and silver. With tetrahedrite in the Australian Broken Hill

Mine, Barrier Range, N.S.W.—In auriferous quartz veins, Band and Albion Mine, Ballarat; Steiglitz; with stibnite, Costerfield, Vic.—Reported from boundary of slate and granite, south-eastern part of Kings Island, Bass Strait.

Var. *Richmondite*, from Richmond Hill, Nelson, N.Z., probably belongs here. It contains in addition to the normal constituents of bournonite some zinc, bismuth, and from 1 to 17 per cent. of silver.

146. NANTOKITE. Isometric; usually granular massive. Cleavage cubical distinct.

H 2·5. G 4·7. Lustre vitreous to adamantine. Colour white to pale grass green. Transparent. On exposure to moist air rapidly decomposes; it exfloresces, becomes at first dark green, afterwards opaque and pulverulent, and ultimately changes to atacamite.

Comp. Anhydrous cuprous chloride, CuCl. Copper 64·18, Chlorine 35·82.

Pyr. F 1. Flame coloration azure blue. On charcoal easily reduced to metallic copper. Gives no water in the closed tube. Gently heated with a drop of water on platinum foil is decomposed to red oxide of copper. Completely soluble in acids and ammonia.

Loc. Owing to its liability to decomposition when acted upon by ammoniacal water, it cannot long exist except in localities in which a low rainfall prevails, and then only in situations above the level of permanent saturation of the country rock. It was first discovered at Nantoko, in Chili. Occurs in the Broken Hill South Mine, Barrier Range, N.S.W., in cuprite, from the alteration of which it has probably been derived, and in the company of native copper and cerussite.

147. ATACAMITE. Rhombic; usually in four-sided rectangular prisms, terminating in domes or rectangular pyramids. Often in twins, made up of three individuals, with diagonal composition planes. Also laminar and massive. Cleavage brachydiagonal perfect, macrodomal

imperfect. Sometimes botryoidal with crystalline surface, and pulverulent.

H 3—3·5. G 4—4·3. Lustre adamantine. Colour dark green. Streak light green. Translucent, sub-translucent.

Comp. Hydrous cuprous chloride, $H_3Cu_2ClO_3$. Copper 59·5, Oxygen 11·2, Chlorine 16·6, Water 12·7; as a rule, however, the amount of water is somewhat larger, usually from 13 to 20 per cent., while that of copper is correspondingly less.

Pyr. F 1, colouring the flame azure blue. On charcoal yields metallic copper. In closed tube gives much water.

Loc. Formed in the upper parts of copper lodes, usually by the action of solutions of chloride of sodium on chalcopyrite or other cupriferous minerals. Mt. Perry; Cloncurry, pseudomorphous after cuprite; Nebo gold-field, Q.—Cobar, Icely, Cowra; in the gossan of silver lodes, Barrier Range, N.S.W.—Finely crystallized at Moonta, Mt. Lyndhurst, Kingston, Yudanamutana, Mutooroo, S.A.—In the caps of silver-lead veins, Dundas and Zeehan, Tas.

148. MARSHITE. Rhombic; modified six-sided prisms, the basal planes alternately striated, giving rise to triangular facets. On account of the rarity of the mineral its crystal form has as yet been only imperfectly studied.

H 3. G 5. Lustre sub-vitreous. Colour brownish pink or flesh-coloured. Streak orange yellow. Fracture subconchoidal. Translucent. Somewhat brittle.

Comp. Cuprous iodide, CuI. Copper 33·3, Iodine 66·6.

Pyr. F 1. In closed tube fuses to a dark-brown mass, evolving violet fumes which condense on the upper part of the tube to a steel-grey crystalline sublimate. In the open tube fuses to a mass which is greenish yellow, and finally purplish black. With soda on charcoal yields a copper bead. Imperfectly soluble in acids.

Loc. The only locality where this rare mineral has been observed is the Broken Hill Lode, Barrier Range, N.S.W., where it occurs in cavities of cerussite with cuprite, chalcocite, malachite, and smithsonite, often coated with ferromanganese.

149. CUPRITE. Isometric: generally in modifications of the cube and octahedron. Often in aggregates of minute brilliant crystals (*ruby copper*). Also granular and compact; sometimes earthy (*tile ore*). Cleavage octahedral distinct.

H 4. G 5·9—6·1. Lustre adamantine, sub-metallic, earthy. Colour cochineal red. Streak shining, brownish red. Translucent to opaque. Fracture uneven. Brittle.

Comp. Suboxide of copper, Cu_2O. Copper 88·8, Oxygen 11·2. The earthy variety, "tile ore," generally contains ferrous oxide, silica, and moisture.

Pyr. F 4. On charcoal reduced to metallic copper. Soluble in HCl; in the concentrated solution H_2O gives a white precipitate of Cu_2Cl.

Loc. Occurs in copper veins both in the gossan zone and below the level of permanent saturation, but becomes rare at greater depth. It results from the oxidation of native copper and the sulphides, and is altered to carbonate and silicate; by deoxidation it reverts to native copper. Cloncurry, Mt. Perry, Morton Island; Kennedy copper-mine, Sandy Creek; with tin ore, Tinaroo, Q.—Cobar, Nymagee, Carcoar; Cadiangulong Mine, Bathurst; Cow Flat, Icely, Peelwood, Broken Hill, N.S.W.—Thompson River copper-mine, Walhalla, Vic.—Well crystallized at Moonta, Kapunda, Mutooroo, Sliding Rock, Spring Creek. Very large crystals were formerly found in the Burra Burra Mine, S.A.—Mt. Lyell, Tas.—D'Urville Island, Aniseed Valley, Nelson, N.Z.—New Caledonia.

150. MELACONITE (*Tenorite*). Monoclinic, in oblique tables or scales with perfect basal cleavage. Also isometric in cubes (pseudomorphous after cuprite?). Mostly amorphous, pulverulent.

H 2—3. G 6—6·2. Lustre metallic to dull. Colour iron black. Soils the fingers.

Comp. Oxide of copper, CuO. Copper 79·8, Oxygen 20·2, generally with some silica, iron, and lime.

Pyr. Infusible. With soda on charcoal reduced to the metallic state. In the concentrated hydrochloric solution H_2O gives no precipitate.

Loc. The black oxide of copper generally occurs with the red oxide, but is much less abundant. Crystallized in the Great Australian copper-mine, Cloncurry. Common in the copper lodes at Mt. Perry; Alliance Mine near Rockhampton; Kennedy Mine near Townsville.—Nymagee, Icely, Carcoar, Wellington, Peelwood, Broken Hill, N.S.W.—Thompson River copper-mine, near Walhalla, Vic.—Doora Mine, Kadina; Currie's Mine, Angaston, S.A.—Penguin, Frankford, Cascade, Tas.

151. MALACHITE. Monoclinic; simple crystals rare, usually contact or penetration twins of four-sided prisms. Cleavage eminently basal, clinodiagonal distinct. Also mammillary, botryoidal, stalactitic, with radial structure; banded; fibrous.

H 3·5—4. G 3·7—4. Lustre vitreous, silky, to dull. Colour bright emerald green. Streak paler than the colour. Sub-translucent to opaque. Fracture uneven.

Comp. Hydrous carbonate of copper, $Cu_2CO_4 + H_2O$. Oxide of copper 71·9 (metallic copper 63·1), Carbonic acid 19·9, Water 8·2. Frequently rendered impure by the admixture of clayey, sandy, and ferruginous matter.

Pyr. F 2. With soda on charcoal gives a copper bead. In the closed tube yields water and carbon dioxide, and turns black. Soluble in HNO_3 with effervescence.

Loc. Common in the upper parts of copper veins. Often impregnates rocks which contain copper pyrites. Cloncurry, Mt. Perry, Palmerston, Blackall, Mt. Orange, Peake Downs, Q.—Cobar, Nymagee, Mt. Hope, Peelwood, Mt. Browne, Carcoar; in the gossan of nearly all the silver lodes in the Barrier Ranges, N.S.W.—Thompson River, St. Arnaud, Landsborough, Vic.—Moonta, Wallaroo, Burra, Kapunda, Mt. Lyndhurst, Blinman, Ediacara, Yudanamutana, S.A.—Heazlewood, Whyte River, Tas.—New Caledonia.

152. AZURITE. Monoclinic; domes, hemidomes, hemioctahedra. Also massive, concretionary, and earthy. Cleavage clinodomal distinct, orthodiagonal imperfect. Basal planes often striated in the direction of the clinodiagonal.

H 3·5—4. G 3·5—3·8. Lustre vitreous, in earthy varieties dull. Colour azure blue to Prussian blue. Streak lighter than the colour. Transparent to opaque. Fracture conchoidal. Brittle.

Comp. Hydrous carbonate of copper, $Cu_3C_2O_7 + H_2O$. Oxide of copper 69·2 (metallic copper 61·4), Carbon dioxide 25·6, Water 5·2. Earthy varieties generally contain clayey, calcareous, and siliceous matter.

Pyr. Like malachite.

Loc. Azurite is frequently derived from malachite through access of carbon dioxide, the alteration proceeding from within towards the surface of the crystal. Pseudomorphs of malachite after azurite have not been observed, and while azurite is rarely met with in the absence of malachite, the occurrence of the latter by itself is common. Cloncurry, Mt. Perry, Sandy Creek, Peake Downs, Tinaroo, Mt. Garnet, Q.—Nymagee, finely crystallized; Cobar, Carcoar, Peelwood; Wiseman's Creek and Cow Flat near Bathurst; Lachlan. Magnificent crystals with malachite and cerussite on ferro-manganese occur in the Broken Hill silver veins, Barrier Range, N.S.W.—Burra, Moonta, Lady Alice, Ediacara, S.A.

153. CHRYSOCOLLA. Amorphous; cryptocrystalline, botryoidal, encrusting, earthy.

H 2—3. G 2—2·2. Lustre vitreous, resinous to dull. Colour bluish green to greenish blue. Streak pale blue, or uncoloured. Transparent to opaque. Fracture conchoidal. Sectile to brittle.

Comp. Hydrous silicate of copper, $CuSiO_3 + H_2O$. Oxide of copper 45·3 (metallic copper 36·1), Silica 34·2, Water 20·5. Usually contains ferric oxide and other impurities, which may considerably reduce the percentage of copper.

Pyr. BB decrepitates but is infusible. In closed tube blackens and yields water. With soda on charcoal reduced to a copper bead. Decomposed by HCl with separation of powdery silica.

Loc. Occurs near the surface of copper veins, often resulting from the action of solutions of alkaline silicates on malachite. Mt. Orange, Dalrymple, Charters Towers, with malachite and copper pyrites.—Cobar, Icely, Wheeo, Broken Hill, N.S.W.—Burra, Wallaroo, Yudanamutana, Mt. Baker, Mt. Lyndhurst, Olary, Ediacara, S.A.—With tin ore and chalcopyrite, Cascade, Tas.—With native gold in a clayey ironstone, Yilgarn, W.A.—D'Urville Island, Aniseed Valley, Nelson, N.Z.

154. CHALCANTHITE (*Blue Vitriol*). Triclinic; modified prisms. Also stalactitic, botryoidal, reniform, and encrusting. Cleavage prismatic imperfect.

H 2·5. G 2·2. Lustre vitreous. Colour azure blue. Streak white. Transparent to translucent. Brittle. Taste metallic, astringent.

Comp. Hydrous sulphate of copper, $CuSO_4 + 5\ H_2O$. Copper oxide 31·8 (metallic copper 25·3), Sulphur trioxide 32·1, Water 36·1. Often mixed with melanterite (iron vitriol), which gives it a greenish tint.

Loc. Occurs in solution in the mine water of most copper districts, and in dry situations efflorescent. Mt. Perry, Herberton, Ravenswood, West Mt. Morgan Mine, Cloncurry, Q.—Millburn Creek copper-mine, Bathurst; Broken Hill, N.S.W.—Thompson River, Walhalla, Vic.—Blinman, Beltana, Ediacara, Mt. Lyndhurst, S.A.—Mt. Bischoff, Gads Hill Range, Tas.

155. CUPROSCHEELITE. Rhombic (?). Crystalline granular. Cleavage perfect.

H 5. G 6. Lustre adamantine to vitreous. Colour bright green to olive green. Streak greenish grey. Fracture uneven. Brittle.

Comp. Tungstate of copper and lime, $CuWO_4 + 2\,CaWO_4$. Copper oxide 8·9 (metallic copper 7·1), Lime 12·6, Tungstic acid 78·5. Generally with a little water.

Pyr. BB fuses at 5 to a black glass. On charcoal the copper is reduced to small globules amidst a black slag which reacts for tungstic acid like scheelite.

Loc. This rare mineral occurs with malachite, azurite, cerussite, and stolzite in the Cordillera silver-mine, Peelwood, N.S.W.

MERCURY GROUP.

The minerals of this group afford characteristic reactions when heated in the closed tube. Native mercury and amalgam yield a sublimate which is made up of minute lustrous globules of metallic mercury, that may be united with the aid of a brush or feather. In the presence of sulphur a black or bluish-black sublimate of sulphide of mercury is formed, and near the assay a mirror of metallic mercury. If arsenic and antimony be also present, the heating must be done gently and gradually, lest the production of a sublimate of the sulphides of these metals mask the earlier reaction for mercury. In the presence of selenium the sublimate is grey, crystalline, and shining. All mercury compounds when mixed with soda and iron filings, and heated in the closed tube, yield a sublimate of metallic mercury. Minute quantities of mercury may be detected by pouring into the tube which contains the sublimate a drop of nitric acid, and then adding quickly a small grain of potassium iodide. On gently heating the bottom of the tube iodide of mercury, rendered conspicuous by its scarlet colour, will be produced.

156. NATIVE MERCURY (*Quicksilver*). Isometric; at a temperature of − 39° F. solidifies and crystallizes in octa-

hedra. Normally it is fluid, and occurs in minute globules which lodge in the pores and fissures of rocks.

H 2 when solid. G 13·56. Lustre metallic. Colour tin white. Opaque. In the solid state malleable.

Comp. Hg; frequently with traces of silver.

Pyr. BB and in the open tube is completely volatilized. Soluble in HNO_3.

Loc. Mercury is perhaps, next to platinum, the rarest of the economically useful metals, its occurrence being confined to a few geographically widely separated localities. Native mercury is probably always a secondary product, derived from the oxidation of cinnabar, which almost invariably accompanies it. Its usual gangue is slate, clay, limestone, and decomposed granite, but it is also found in cavities of vein-quartz and other massive rocks. Kilkivan, Q., in quartzite.—Dungog, Carwell Creek, Cudgegong River; Ophir, Boorook, N.S.W.—Jamieson, Vic., in talcose slate.—North of Linda River, near Mt. Lyell, Tas.—In mud sediments with sulphur at the mouth of a thermal spring at Ohaewai, N.Z.—The quicksilver of commerce is chiefly obtained from cinnabar.

157. CINNABAR. Hexagonal; six-sided prisms, modified by planes of the rhombohedron and pyramid. Also granular, massive, encrusting, earthy, and in rolled fragments. Cleavage prismatic perfect.

H 2—2·5. G 9. Lustre adamantine to dull. Colour cochineal red to brownish red, sometimes greyish. Streak scarlet red. Translucent to opaque. Fracture uneven. Sectile.

Comp. Sulphide of mercury, HgS. Mercury 86·2, Sulphur 13·8. Often rendered impure by oxide of iron, carbonaceous or clayey matter.

Pyr. BB volatilizes. In the open tube gives vapours of sulphur, and a sublimate of metallic mercury.

Loc. Occurs chiefly in limestone, sandstone, bituminous shale, and quartz. Kilkivan, Q., in veins varying from a few inches to seven feet in thickness, traversing porphyry; the gangue of the veins is calcareous, and contains quartz and calcite, through which the cinnabar is distributed. Mt. Biggenden, Q., in quartzose veins traversing amphibole rock in proximity to granite.—Rylstone, on the Cudgegong River, N.S.W.; the mineral occurs here in an argillaceous gangue, as well as in the form of rolled pebbles with native gold, in pliocene sand and quartz pebble drift which rests on Devonian shales and sandstones. Grove Creek, Abercrombie Range. Mookerawa and Great Waterhole of Ophir, County of Westmoreland. Horseshoe Bend and Yulgilbar Station, Clarence River. In the last-mentioned locality the mineral occurs in dyke-like masses of felsite, the country rock being hornblendic granite and augite diorite. The cinnabar is associated with quartz orthoclase, calcite, pyrite, and tetrahedrite. Spring Creek, near Bingera. Also reported from Moruya, N.S.W.—Between Lake Wakitupu and the Shotover River, Otago, N.Z., in foliated schist country; the sloping surface is abundantly strewn with fragments of cinnabar, while the basset of the bed-rock is frequently stained by the mineral, but the parent deposit has not been discovered. Sintery hepathic cinnabar is found in a thermal spring at the Bay of Islands, N.Z. The following are the principal quicksilver producing countries of the globe: Almaden in Spain; bedded veins in bituminous slate of Upper Silurian age.—Clear Lake region, California; zones of impregnation in tertiary limestone; also superficial deposits around thermal sulphur springs.—Idria, in the Austrian Alps; impregnating black bituminous shale and limestone of carboniferous age.—Modena, Italy; disseminated in talcose mica schist with bands of quartz.—Rhenish Bavaria; in lodes and impregnations in Permian conglomerate.—Borneo in quartzose veins, and rolled pieces.

158. Calomel (*Horn Quicksilver*). Tetragonal; prisms with octahedral replacement of lateral edges. Cleavage diagonal imperfect.

H 1·5. G 6·5. Lustre adamantine. Colour white, grey, brown. Streak white or yellowish. Translucent to opaque. Fracture conchoidal. Sectile.

Comp. Chloride of mercury, Hg_2Cl. Mercury 84·9, Chlorine 15·1.

Pyr. BB on supports volatilizes, and forms a white sublimate. In KHO blackens. Taken up in the micro. salt bead, charged with oxide of copper, and fused imparts an azure-blue colour to the blowpipe flame. Soluble in HNO_3; in the solution silver nitrate throws down a white precipitate of chloride of silver.

Loc. In the gossan of quicksilver lodes with cinnabar in several of the localities mentioned above.

159. COCCINITE (*Onofrite*). Rhombic (?), granular, earthy.

H 1—2. G 5·5. Lustre vitreous to dull. Colour scarlet red to brick red, turning bluish grey on exposure.

Comp. Iodide of mercury, Hg_2I. Mercury 75·9, Iodine 24·1.

Pyr. BB volatile. Fused with potassium bisulphate in the closed tube yields violet fumes of iodine, and a sublimate of metallic mercury.

Loc. At Broken Hill, Barrier Range, impregnating kaolinitic clay, which also harbours iodyrite and cerargyrite, together with pale-brown garnet and blebs of quartz. It gives reactions of chlorine and selenium, and may be a mixture of onofrite, Hg(S, Se), cerargyrite, AgCl, and iodyrite, AgI.

LEAD GROUP.

The minerals of this group are specifically heavy and easily fusible. Heated on charcoal they deposit a coating of lead oxide which is dark lemon yellow while hot and sulphur yellow when cold, and has a bluish-white fringe of carbonate or sulphate of lead. The sublimate is easily volatilized, and colours the blowpipe flame pale azure blue. All are easily reduced to the metallic state when fused on charcoal with soda, and in some cases without soda. They are soluble in nitric acid.

160. NATIVE LEAD. Isometric; generally in thin plates. Also in rolled pieces.

H 1·5. G 11·44 when pure. Lustre metallic. Colour lead grey. Streak grey, shining. On exposure tarnishes to dull ash grey. Malleable, ductile.

Comp. Pure lead, Pb.

Pyr. F 1. On charcoal gives a yellow incrustation; the fused globule on solidifying is surrounded by a coating of oxide.

Loc. Washed grains occur in detrital deposits at Peelwood, Gundagai, Captain's Flat, Snowy River, N.S.W.—In middle pliocene gold-drift at Ballarat, Creswick, Daylesford, Avoca, Vic.—In flattened plates in silver-lead veins at Dundas, Tas.

161. GALENITE (*Galena*). Isometric; usually combinations of the cube and octahedron, frequently twins like Fig. 129. Also granular, cryptocrystalline, laminated, reticulate, rarely fibrous. Cleavage cubic very perfect.

H 2·5. G 7·5. Lustre metallic. Colour and streak lead grey. In moist situations often takes an iridescent tarnish. Fracture smooth.

Comp. Sulphide of lead, PbS. Lead 86·6, Sulphur 13·4. Usually contains some silver, frequently also copper, antimony, zinc, arsenic, etc. Such impurities are often due to mechanical admixture of argentite, chalcocite, stibnite, arsenopyrite, pyrite, etc.

Pyr. F 1. In the open tube yields fumes of SO_2. On charcoal reduced without flux.

Loc. Galena is the most abundant of lead ores, and is invariably argentiferous. It has been observed in pseudomorphs after pyromorphite and some other mineral with octahedral cleavage. This is a singular circumstance, since no other metallic sulphide is known to occur in nature pseudomorphous after an oxidized compound of the metal it contains. There is, on the contrary, a very large number of minerals which occur pseudomorphous after galena, *e.g.* cerussite, pyromorphite, anglesite, tetrahedrite, chalcocite, pyrite, calamite, limonite, quartz.

Galena can be produced in the laboratory both in the dry and the wet ways, and there can be no doubt that its existence in nature is likewise due partly to sublimation and partly to precipitation from solutions. Its distinctly volcanic origin has been noticed in Vesuvian lavas, where it is formed by the action of SH_2 upon $PbCl_x$ in part perhaps also by the heating of oxide or silicate of lead in the presence of vapours of sulphur. On the other hand, it constitutes the petrifying medium of organic remains, such as bivalves in Triassic sandstone, belemnites in Liassic limestone, fronds of ferns in the coal-measures, etc. In these cases the galena probably resulted from solutions of sulphate of lead melting with sulphides of alkalies or alkaline earths, or with SH_2. If sulphate of lead comes in contact with carbonated water in which fermentation is kept up by the presence of decaying organic matter, galena will be produced and, in the case of shell-fish, deposited on the shell, the carbonate of lime of which the latter is composed being ultimately wholly removed by solution, and its place occupied by sulphide of lead.

Galena occurs in veins and zones of impregnation chiefly in connection with crystalline rocks, foliated schists, and limestone. It commonly accompanies ores of silver, zinc, gold, etc., and is so widely distributed throughout the mining fields of Australia that reference need be made to such localities only as afford the mineral in deposits of economic importance. Ravenswood, Hodgkinson, Silverfield, Mount Albion, Chowy Creek, Q.—Emmaville, Glen Innes, Inverell, Silverdale, Mitchell's Creek, Fairfield, Broken Hill, Silverton, N.S.W.—St. Arnaud; in auriferous quartz veins throughout the Victorian gold-fields.—Ediacara, Beltana, Manna Hill, Wadnaminga, Wirrialpa, Rapid Bay, Macdonnell Range, Port Darwin district, S.A.—Dundas, Zeehan, Heazlewood, Whyte River, Waratah, Penguin, Tas.—Geraldine, Northampton, Oakajee, Victoria district; Irwin River, Kimberley, W.A.—Thames, Ohinemuri, Collingwood, Wangapaka, N.Z.

162. JAMESONITE. Rhombic, generally in acicular prisms. Also in divergent or parallel fibrous aggregates; capillary (*Feather Ore*); rarely massive. Cleavage basal perfect.

H 2·5. G 5·6. Lustre metallic. Colour and streak dark lead grey. Frangible.

Comp. A double salt of sulphide of lead and sulphide of antimony, $2\ PbS + Sb_2S_3$. Lead 50·6, Antimony 29·9, Sulphur 19·5; usually with some iron, frequently also traces of copper, zinc, and bismuth.

Pyr. F 1. Decrepitates. On charcoal all but completely volatilized. In the open tube emits fumes of antimony and sulphurous acid. With soda on charcoal reduced to metallic lead.

Loc. Associated with galena in argentiferous and auriferous quartz. Campbell's Creek and Nuggetty Gully, near Bathurst, N.S.W.—Feather ore, hair-like acicular crystals, at Waratah, Tas. Feather ore with boulangerite, galena, massicot, and cerussite on brownspar and siderite at Dundas, Tas.

163. BOULANGERITE. Rhombic (?); no distinct crystals observed; crystalline, granular, capillary.

H 2·5—3. G 5·8. Lustre metallic. Colour and streak lead grey.

Comp. Sulphide of lead and antimony, $3\ PbS + Sb_2O_3$. Lead 58·7, Antimony 23·1, Sulphur 18·2. Often with small portions of iron, copper, zinc, or silver.

Pyr. Like jamesonite.

Loc. Occurs under similar conditions to jamesonite. In auriferous quartz veins, Band and Albion Mine, Ballarat, and Albion Mine, Steiglitz, Vic.—St. Clare Mine, Kainantoo, S.A.—Waratah and Dundas, Tas., with jamesonite.

164. **BOLEITE.** Isometric; cubes and octahedra, often macled. Cleavage cubic distinct.

H 3. G 5. Lustre vitreous. Colour indigo blue. Streak lighter than the colour. Translucent, sub-transparent. Brittle.

Comp. Hydrated oxychloride of lead and copper and chloride of silver, $3\,(PbClH_2O, CuClH_2O) + AgCl$. Lead 47·4, Copper 19·2, Silver 8·3, Chlorine 13·5, Oxygen 6·1, Water 5·5.

Pyr. F 1; colouring the flame emerald green with streaks of azure blue. On charcoal yields globules of lead and copper. In closed tube gives water.

Loc. The occurrence of this rare mineral was only known from Boleo, Santa Rosalia, Lower California, until its recent discovery in the Broken Hill South Mine, Barrier Range, N.S.W., where some finely-crystallized specimens have been obtained. It occurs here with cerussite, cerargyrite, and malachite in the gossan of the Broken Hill silver lode, at a depth of some hundred feet.

165. **MASSICOT** (*Lead Ochre*). In scales or earthy.

H 2 or less. G 7·9. Lustre dull. Colour lemon to sulphur yellow. Streak pale yellow. Opaque.

Comp. Protoxide of lead, PbO. Lead 92·8, Oxygen 7·2; often contains carbonic acid, oxide of iron, calcareous, siliceous, or clayey matter.

Pyr. BB fuses at 1 to a yellow glass. On charcoal gives a lead globule. Artificially-produced crystals show that protoxide of lead is dimorphous, viz. rhombic and isometric, the different forms being apparently dependent on the conditions under which the substance solidifies and cools.

Loc. Occurs in the gossan of galena veins at Ravenswood, Herberton, and other lead-mining districts of Northern Queensland.—At Dundas, Tas., with boulangerite, cervantite, and limonite, an association which clearly indicates its origin.

166. MINIUM (*Red Lead*). Amorphous; cryptocrystalline or pulverulent.

H 2·5. G 4·6. Lustre dull to sub-resinous. Colour scarlet red. Streak orange red. Opaque.

Comp. Peroxide of lead, Pb_3O_4. Lead 90·7, Oxygen 9·3.

Pyr. F 1. Easily reduced on charcoal.

Loc. Minium has been observed in crystals pseudomorphous after galena and cerussite. Occurs in the gossan of lead veins. Peelwood, Gundagai, Captain's Flat; Mt. Trooper, Snowy River, N.S.W.—Dundas, Whyte River, Tas.

167. CERUSSITE (*White Lead Ore*). Rhombic; six and eight-sided prisms, terminating in domes. Crystals usually broad and thin. Penetration twins of three and six individuals common. Also granular, massive, and earthy; rarely stalactitic or fibrous. Cleavage prismatic distinct.

H 3. G 6·47. Lustre adamantine, pearly to resinous. Colour white, grey, greyish black. Streak white. Transparent to translucent. Fracture conchoidal. Brittle.

Comp. Anhydrous carbonate of lead, $PbCO_3$. Lead oxide 83·5 (metallic lead 77·5), Carbon dioxide 16·5. Frequently contains silver, iron, copper, etc.

Pyr. F 1. Decrepitates. On charcoal easily reduced. Heated in the closed tube becomes at first yellow, later red, and when cold again yellow. Dissolves with effervescence in HNO_3.

Loc. Occurs in the upper parts of lead veins, often with carbonate of copper and zinc. Galena attacked by an acid solution of iron vitriol (such as would result from the oxidation of iron pyrites) forms sulphate of lead, which in contact with solutions of carbonates (or water charged with carbonic acid) is altered to carbonate of lead. Thus 100 parts of galena suffice to produce 126·8 parts of sulphate of lead, and 111·7 parts of carbonate of lead. If copper pyrites be present, a basic hydrated sulphate of copper is formed which is ultimately converted into malachite or azurite.

The extent of the cerussite deposits in the Barrier Ranges and their general richness in silver are unparalleled in any other mining field of the world. In the most important mine, that of the Broken Hill Proprietary, mining operations have laid bare great bodies of this mineral, extending from the surface to a depth of upwards of 300 feet, and occupying in places the entire space of the lode fissure, which is not rarely 110 feet in width. Most of this ore has yielded at the rate of from ten to thirty ounces of silver to the ton. The question whether the silver is in the metallic state, deposited on capillary joints and cleavage planes of the cerussite, or whether it exists as a carbonate, has been as yet by no means satisfactorily answered. That there exists some kind of relation between the structure of the mineral and its contents in silver seems to have been long recognized by metallurgists. As a rule cerussite crystallized in bladed penetration twins (the usual form at Broken Hill) is a strong carrier of silver, whereas the variety occurring in the form of bundles of simple rhombic prisms contains little or no silver. The latter circumstance has been proved even in localities, *e.g.* Western Tasmania, where the galena, whence the cerussite may be assumed to have been derived, is known to be highly argentiferous.—Ravenswood (yielding 150 oz. of silver to the ton of cerussite), Argentine silver-field, Herberton, Q.—Barrier Ranges, Peelwood, Fairfield, Lewis Ponds, Emmaville, Silverdale, N.S.W.—St. Arnaud, Buchan River, Vic.—Ediacara, Beltana, Olary, Manna Hill; Talisker Mine, Cape Jervis; Port Darwin district, S.A.—Dundas, Zeehan, Whyte River, Heazlewood, Tas.—Geraldine, Northampton, W.A.

168. Pyromorphite. Hexagonal; six-sided prism, often barrel-shaped. Prismal faces horizontally striated. Frequently in groups of tapering hexagonal prisms terminating in botryoidal aggregates. Also reniform, granular massive, fibrous or earthy. Cleavage prismatic imperfect.

H 3·5. G 6·5—7. Lustre resinous. Colour green, greyish green, brown, yellow; rarely white. Streak white or but slightly coloured. Translucent. Fracture uneven. Brittle.

Comp. Chloro-phosphate of lead. $3\ Pb_3P_2O_8 + PbCl_2$. Lead oxide 74·1, Lead 7·6 (total metallic lead 76·4). Phosphoric acid 15·7, Chlorine 2·6. Part of the lead is often replaced by calcium, and part of the phosphorus by arsenic, and so passes into mimetite.

Pyr. F 1·5, colouring the flame green from phosphoric acid. On charcoal fuses to an enamel-like globule, which on cooling is covered with numerous shining facets. With soda on charcoal reduced to metallic lead. Fused with micro. salt and copper imparts an azure blue colour to the blowpipe flame. In the cold nitric solution molybdate of ammonia throws down a yellow granular precipitate.

Loc. Pyromorphite occurs in veins with other lead ores. Ravenswood, Burdekin, Gilbert, Ruby rivers, Q.—Silverdale near Bowning, Bathurst, Grenfell, Sugarloaf Hill near Wellington, Broken Hill, N.S.W.—St. Arnaud, Castlemaine, Campbell's Reef near Moyston, Vic.—Strathalbyn, Avondale, Ediacara, Farina; Flora Bell, Darwin district, S.A.—Zeehan, Heazlewood, Whyte River, Tas.—Geraldine, Northampton, W.A.—Pyromorphite and galena have been observed in pseudomorphs one after the other.

169. MIMETITE. Hexagonal. Crystals like pyromorphite. Cleavage rhombohedral imperfect. Also fibrous, concretionary, and pulverulent.

H 3·5. G 7—7·2. Lustre resinous. Colour sulphur yellow, orange, brown; rarely white. Streak white, yellowish. Transparent to translucent.

Comp. Chloro-arsenate of lead, $3\ Pb_3As_2O_8 + PbCl_2$ Lead oxide 67·4, Lead 7 (total metallic lead 69·6), Arsenic acid 23·2, Chlorine 2·4. Part of the lead often replaced by calcium (*Hedyphane*), and part of the arsenic by phosphorus (*Campylite*), and thus passing into pyramorphite.

Pyr. F 1. On charcoal yields arsenical vapours, and is reduced without the aid of a flux. With micro. salt and copper reacts for chlorine like pyromorphite.

Loc. Occurs in veins with other ores of lead. Riverton, Q., in a pulverulent form and highly argentiferous; probably a mixture.—Peelwood, Gulgong, Silverdale, Sugarloaf Hill near Wellington, N.S.W. In the Central Broken Hill Mine, Barrier Range, at a depth of 200 feet, finely crystallized in pale yellow, almost colourless, hexagonal prisms surmounted by pyramids, associated with cerussite on ferro-manganese. In the Broken Hill Proprietary Mine, in the same locality, it occurs in capillary aggregates with cerussite and iodyrite. —St. Arnaud; Murindal, Gippsland, Vic.—Hampshire silver-mine, Tas.

170. VANADINITE. Hexagonal; six-sided prisms with terminal edges replaced by planes of the pyramid. Crystals rare; generally globular or botryoidal.

H 3. G 6·9. Lustre resinous. Colour reddish brown, brownish yellow. Streak white or yellowish. Translucent to opaque. Fracture uneven. Brittle.

Comp. Chloro-vanadate of lead, $3\ Pb_3V_2O_8 + PbCl_2$. Lead oxide 70·9, Lead 7·3 (total metallic lead 73·1), Vanadic acid 19·3, Chlorine 2·5.

Pyr. F 1. On charcoal reduced to a metallic globule, which after continued heating in the OF leaves a black slag of vanadic oxide. The latter treated with borax or micro. salt on platinum wire yields a glass which in the OF is dark yellow while hot and pale yellow when cold, and in the RF brownish while hot and chrome green when cold. Fused with micro. salt and copper colours the flame azure blue. Soluble in HCl and HNO_3. To the concentrated hydrochloric solution alcohol imparts an emerald-green colour.

Loc. This rare mineral, hitherto only known to occur in Arizona, U.S.A., Mexico, and the Ural, has been recently discovered at Silverton, Barrier Range, N.S.W., and is also reported from the Bells Reward Mine, Heazlewood, Tas.

171. ANGLESITE (*Lead Vitriol*). Rhombic; oblong or

tabular prisms modified by domes; octahedral. Also granular, massive; rarely stalactitic. Cleavage prismatic and basal indistinct.

H 3. G 6·3. Lustre adamantine. Colour white, colourless; sometimes faintly tinged by metallic oxides. Streak white. Transparent to nearly opaque. Fracture conchoidal. Brittle.

Comp. Anhydrous sulphate of lead, $PbSO_4$. Lead oxide 73·6 (metallic lead 68·3), Sulphuric acid 26·4. Generally with traces of water.

Pyr. F 1·5. Decrepitates. On charcoal in OF fuses to a colourless glass, which cools to a white enamel. With soda on charcoal gives an hepar and a globule of lead. Dissolves only difficultly in HNO_3.

Loc. Anglesite is an alteration product of galena. It occurs pseudomorphous after calcite, and has been observed as the petrifying medium of fossil mollusca, *e.g. gryphæa* in Jurassic strata at Sienna in France. On the other hand, the occurrence of pseudomorphs of cerussite after anglesite shows its liability, in common with other sulphates, to be transformed into a carbonate. Like cerussite it is sometimes highly argentiferous, as at Ravenswood, Q., and Western Tasmania, where the galena from which it is derived is particularly rich in silver.—Star River, Tinaroo, Townsville, Q.—Lewis Ponds near Orange, Wiseman's Creek, Campbell's Creek, Severn River, N.S.W. In the Junction Mine, Broken Hill, it occurs in small but well-formed crystals with cerussite and native copper on quartziferous ironstone, the whole coated with carbonate of copper. In McGregor's shaft of the Broken Hill Proprietary Mine, at a depth of 310 feet, stout rhombic prisms on galena.—Glendhu near Landsborough; St. Arnaud, Vic.—Wilpena Pound, Ediacara. In the Flora Bell Mine, Northern Territory, S.A., it occurs stalactitic, often showing a nucleus of galena.—Whyte River, Zeehan, Dundas, Tas. Large and very regular crystals have been obtained in the Maestrie's Mine in the last-mentioned locality.

172. CROCOITE (*Chrome Lead Ore*). Monoclinic; four-sided prisms surmounted by domes, hemidomes, or hemipyramids. Also columnar and granular. Cleavage prismatic imperfect. Primal faces vertically striated.

H 3. G 6. Lustre adamantine. Colour brilliant hyacinth red to brownish red. Streak orange yellow. Translucent. Fracture uneven. Sectile.

Comp. Chromate of lead, $PbCrO_4$. Lead oxide 68·9 (metallic lead 64), Chromic acid 31·1.

Pyr. F 1·5. Decrepitates, turns black, but resumes its red colour on cooling. On charcoal yields a lead globule, together with a residue of chromic oxide, which imparts an emerald-green colour to the fluxes in OF and RF.

Loc. Occurs with other lead ores in fine groups of crystals, as well as in fibrous aggregates with stilpnosiderite and ferro-manganese at Dundas, Zeehan, Heazlewood, and Whyte River in Western Tasmania.

173. STOLZITE. Tetragonal; truncated acute octahedra, often in confused crystalline aggregates. Cleavage basal imperfect, octahedral indistinct.

H 3. G 7·9—8·1. Lustre resinous to vitreous. Colour brown, red, green, grey. Streak white. Sub-translucent. Fracture uneven. Brittle.

Comp. Tungstate of lead, $PbWO_4$. Lead oxide 49 (metallic lead 45·5), Tungstic acid 51; generally with some lime, protoxide of iron, and manganese.

Pyr. F 2. Decrepitates. With soda on charcoal gives metallic lead. On removal of the lead globule and fusing the residue with a fresh supply of soda the coal will be covered with tungstate of soda, which has a metallic lustre. The fused mass boiled in HCl with a fragment of tin or zinc yields a blue solution. The micro. salt bead is colourless in OF, and greyish green while hot, blue when cold in the RF. Fused with chloride of tin in the RF the micro. salt bead becomes dark green when cold. From the nitric solution tungstic acid separates in the form of a yellow powder.

Loc. Occurs crystallized in modified octahedra, associated with cerussite, anglesite, smithsonite, and psilomelane in the Broken Hill Proprietary Mine, Barrier Range. Also with cerussite on cuproscheelite in the Cordillera silver-mine, Peelwood, N.S.W.

174. WULFENITE. Tetragonal; octahedral, square and octagonal tables, often modified by planes of the pyramid (Fig. 64). Also granular massive. Cleavage octahedral perfect, basal imperfect.

H 3. G 6—7. Lustre resinous to adamantine. Colour straw yellow, brown, green, greyish green; vanadiniferous varieties orange yellow to red. Streak uncoloured. Translucent. Fracture sub-conchoidal. Brittle.

Comp. Molybdate of lead, $PbMoO_4$. Lead oxide 61·5 (metallic lead 57·1), Molybdic acid 38·5. Usually contains some lime and vanadic or chromic acid.

Pyr. F 1·5. With soda on charcoal reduced to lead. Fused with micro. salt in OF the bead is yellowish green while hot, and colourless when cold; in RF greyish green while hot, and bright green when cold. The last-mentioned reaction in RF is more distinct in borax than in micro. salt. Decomposed by HCl with separation of chloride of lead. The green-coloured hydrochloric solution, when diluted with water and boiled with a fragment of metallic tin, turns blue.

Loc. Found sparingly with other lead ores in the gossan of lead veins. Broken Hill Mine, N.S.W., greyish-white obtuse octahedra on galena.—Avondale Mine, Farina, S.A.

TIN GROUP.

175. NATIVE TIN. Tetragonal; natural crystals not known. Occurs in flattened grains.

H 2. G 7·3. Lustre metallic. Colour tin white. Malleable, ductile. Emits a sound when bent.

Comp. Sn, with traces of lead.

Pyr. F 1. On charcoal gives close to the assay a coating of oxide which is faintly yellow while hot, and pure white when cold. The sublimate phosphoresces in the OF, but is non-volatile; moistened with cobalt solution and ignited in the OF it acquires a bluish-green colour on cooling.

Loc. The occurrence of metallic tin in nature is not free from doubt. Reported from Oban, N.S.W., in the auriferous sand of the Aberfoil River.

Econ. Of impurities lead is the least objectionable, since it merely imparts a darker and duller appearance to the tin, without materially affecting its ductility. Copper, iron, arsenic, and bismuth, even if present to the extent of only one-half per cent. (in the aggregate), cause brittleness, and lower its marketable value.

176. CASSITERITE (*Tin Stone*). Tetragonal; square pyramids with or without intermediate prism (Fig. 62). Often macled. Also granular, massive, disseminated, and in rolled fragments. Cleavage prismatic very indistinct.

H 6·5. G 6·5—7. Lustre of crystals adamantine, splendent; of massive varieties vitreous to resinous. Colour greyish or bluish black, brown, red, yellow, white, mottled. Streak greyish or yellowish white. Translucent to opaque. Fracture uneven. Brittle.

Comp. Binoxide of tin, SnO_2. Tin 78·7, Oxygen 21·3, generally with some oxide of iron and manganese, siliceous and clayey matter.

Pyr. BB infusible. With soda on charcoal reduced, with the formation of a white sublimate of oxide. The minute pellicles of metallic tin sink into the charcoal beneath the soda. This portion of the coal having been moistened with a few drops of water and cut out with a knife to a depth of at least a quarter of an inch, should then be transferred to the agate mortar and triturated with water. The coal powder, soda, and other impurities are washed off, while the tin collects in flattened shining spangles. (See further under *Stannite.*)

Loc. The mode of occurrence of cassiterite is threefold, viz. (1) as a primary constituent of certain granitic rocks (tin granite); (2) in zones of impregnation and veins, chiefly in granite, sometimes in altered sedimentary rocks in close proximity to granite; (3) in detrital deposits. Under the two first-mentioned conditions the mineral is spoken of as *lode tin* or *mine tin;* in the third case as *stream tin* or *alluvial tin.* The paragenetic relations of cassiterite are perhaps better understood than those of any other ore. The order in which the minerals usually associated with lode tin have been formed appears to be the following: Quartz and tourmaline were the first produced; next cassiterite, then successively wolfram, arsenopyrite, molybdenite, apatite, fluorite, topaz, sulphides of copper, iron, and bismuth, and lastly chlorite and kaolin.

The circumstance that lode tin is rarely found in compact masses, whereas solid, rolled blocks of a hundredweight and more are not uncommon in alluvia, suggests the question, already raised in connection with gold nuggets, whether such masses may not be the result of growth in the drift (by deposition from solutions upon a nucleus). Stream tin is as a rule purer than lode tin, and accordingly commands a higher price in the market. In accounting for this difference in composition it is commonly assumed that stream tin has lost most of the natural impurities, especially sulphides and tungstates, by a prolonged process of oxidation and washing; but it is not explained how such a superficial action could affect the internal part of a compact mass that may measure several feet in diameter. That binoxide of tin is held in solution by drift waters is demonstrated by the occurrence in Cornwall of deer's antlers entirely converted into cassiterite.

Ruby tin is a miners' term for a red, sub-transparent variety occurring in minute splendent crystals. *Rosin tin* has a strong resinous lustre. *Wood tin* has a concretionary structure, is internally coarsely fibrous, often of several shades of yellow or brown, and resembles dry wood.

The most productive tin-fields of the globe lie in a belt of country occupied by granite and crystalline schist, which extends from Pegu southward through Siam, the Malay Peninsula (Penang, Perak, Malacca), the islands of Singapore, Banka, Billitong, the south-eastern part of Sumatra, and the western part of Java. Its southern prolongation may be looked for in Western Australia. Another stanniferous tract extends along the coast range of Eastern Australia, from York Peninsula on the north to the Blue Tier in Tasmania on the south, productive tin-fields having been opened in nearly every part of this range of upheaval, where the fundamental granite comes to the surface.—Tinaroo district, Stanthorpe, Cannibal Creek near Maytown, Q.—Glen Creek, Vegetable Creek, Ding Dong, Elsmore, Newstead, Stannifer, and elsewhere in the New England district. In chlorite dykes at Paradise Creek, Mole Tableland; Poolamacca, Waukaroo, Barrier Range; Jinjellic, N.S.W.—Beechworth district; Wombat, Omeo, Baw Baw Range, Vic.—Port Darwin district, Northern Territory. Daly River district. Mt. Shoobridge; Anne River, McKinlay, Mt. Lynes; Bynoe Harbour; Finniss River, S.A.—Blue Tier, Ringarooma, Ben Lomond, Eastern Tasmania. Mt. Bischoff, Pieman River, Mt. Ramsay, Western Tasmania.—Flinders Island.—Greenbushes, Blackwood River; between the Preston River on the north to Bridgetown on the south. Between Pilbarra and Nullagine, W.A.

177. STANNITE (*Tin pyrites*). Isometric (Tetragonal?). Prisms like cubes, square octahedra. Crystals rare and indistinct; usually disseminated in grains. Cleavage cubic and dodecahedral imperfect.

H 4. G 4·4. Lustre metallic. Colour and streak iron black; often externally tarnished blue. The yellow colour sometimes seen is due to admixture of copper pyrites. Fracture uneven. Brittle.

Comp. Sulphide of tin, copper, and iron, $SnCu_2FeS_4$. Tin 27·5, Copper 29·5, Iron 13, Sulphur 30. Frequently contains zinc.

Pyr. F 1. Decrepitates. In the open tube, and on charcoal in OF, emits sulphurous vapours. The roasted assay gives with the fluxes reactions for copper and iron. With soda on charcoal forms an hepar and a coating of oxide of tin. The part of the coal containing the reduced metals may be treated in the mortar as for cassiterite; since the amount of tin, however, is minute, a confirmatory test is advisable. The triturated metallic particles in the agate mortar are moistened with a few drops of strong HCl, a drop of strong solution of auric chloride is added, and the mixture stirred, when the bottom of the mortar will shortly be covered with a red precipitate of purple of Cassius. Another method of determining small quantities of tin is the following. The assay is taken up in a borax bead, which has been *slightly* coloured by oxide of copper, and fused for a short time in OF. If tin is present the oxide of copper is reduced to suboxide, and the bead appears opaque red on cooling. Decomposed by HNO_3 with separation of sulphur and oxide of tin.

Loc. Tinaroo, Q., with cassiterite, sphalerite, and copper pyrites. — Reported from Inverell, N.S.W. — Shoobridge, Bynoe Harbour, Northern Territory.—Reported from Barossa Range, S.A.—Mt. Bischoff, Tas.

ZINC GROUP.

178. Native Zinc. Hexagonal; in artificial crystals. Massive and in rolled pieces. Cleavage basal perfect.

H 2. G 7. Lustre metallic. Colour greyish white, on exposure becomes bluish white from oxidation. Rather brittle.

Comp. Zn; usually with some cadmium, bismuth, lead, etc.

Pyr. F 2. In the forceps BB ignites, colours the flame intensely whitish green, and is converted into white oxide. On charcoal in RF deposits at some distance from the assay a sublimate which is yellow while hot and white when cold. The sublimate glows in the OF, but is not volatilized; moistened with cobalt solution and ignited in the OF it becomes yellowish green on cooling.

Loc. Reported from the Carpentaria district, Q.—Said to have been found in a cavity in basalt at Collingwood near Melbourne; the specimen was described as being a pound and a half in weight and covered with aragonite. Waterworn pieces have been repeatedly discovered in refuse heaps on the sites of alluvial gold-workings in the Ovens district, at Creswick and elsewhere in Victoria, and at Forest Range, S.A. Bearing in mind, however, that zinc is largely employed in the appliances used by miners, and that the alleged discoveries have not been made by scientific observers, its occurrence in a native state is still doubtful.

179. SPHALERITE (*Zinc Blende*, *Black Jack*). Isometric; rhombic dodecahedron; cube with solid angles replaced; tetrahedron, often with replaced edges; macled dodecahedron with the plane of composition parallel to a face of the octahedron. Also mammillary, granular compact; rarely fibrous, divergent. Cleavage dodecahedral highly perfect.

H 4. G 3·9—4·2. Lustre resinous to sub-metallic, splendent. Colour brown, black, red, yellow, rarely white. Streak yellowish white. Transparent to sub-translucent. Fracture conchoidal. Brittle.

Comp. Sulphide of zinc, ZnS. Zinc 67, Sulphur 33. Part of the zinc generally replaced by iron. The highly ferriferous variety ***marmatite*** contains sometimes as much as 18 per cent. of iron. Frequently also contains cadmium, manganese, tin, silver, and gold.

Pyr. F 6. Decrepitates. In the open tube and on charcoal, after prolonged heating, gives sulphurous fumes. With soda on charcoal yields an hepar, and a coating of oxide of zinc, which is yellow while hot and white when cold. (When cadmium is present a red-brown sublimate is formed at an earlier stage.) The zinc coating moistened with cobalt solution and heated in OF acquires a yellowish-green colour when cold. Decomposed by HCl with separation of sulphur and evolution of H_2S.

Loc. Occurs in mineral veins, usually associated with galena, pyrite, siderite, chalcopyrite, pyrrhotite, and quartz. Charters Towers, Tinaroo, Norton, Rockhampton, Q., generally gold-bearing. Ravenswood, marmatite, both argentiferous and auriferous.—Tenterfield, Emmaville, Fairfield, Mitchell's Creek, Adelong, Cow Flat, Pye's Creek, Silverdale. Marmatite at Sunny Corner. Auriferous at Braidwood. Argentiferous at Armidale; Pinnacles, Thackaringa, Broken Hill, Barrier Ranges, N.S.W.—Almost universally, though sparingly, disseminated in auriferous quartz veins in Victoria. Abundant in silver veins, St. Arnaud.—With argentiferous galena at Aclare Mine, Calilington; Mt. Lofty, Wheal Ellen, Mt. Barker. With gold at Teetulpa. With copper at Moonta and Wallaroo, S.A.—Zeehan, Dundas, Whyte River, Waratah, Penguin, Mt. Claude, Lefroy, Castray River, Scamander, Tas.—Geralton, Cardup, south of Perth, W.A. —Thames, Collingwood; Te Aroha, Auckland, N.Z.—At Webb City, Missouri, U.S.A., sphalerite occurs in extensive lenticular masses with jasper in Devonian limestone. At St. Louis in the Mississippi valley a lenticular deposit of lignite in mesozoic sandstone is traversed by numerous joints and fissures filled with sphalerite. In this case the sandstone had been apparently permeated with solutions of zinc sulphate, which by the reducing action of the carbonaceous matter was precipitated in the cracks of the lignite.

180. ZINCITE (*Red Zinc Ore*). Hexagonal; six-sided prism with truncated pyramids. Crystals rare, usually in cleavage scales; also granular and massive. Cleavage basal highly perfect.

H 4. G 5·6. Lustre vitreous. Colour scarlet red to orange yellow. On exposure becomes coated with white carbonate. Streak orange. Translucent. Fracture subconchoidal. Brittle.

Comp. Oxide of zinc, ZnO. Zinc 80·26, Oxygen 19·74. Usually with some oxide of manganese, to which the red colour is probably due, and oxide of iron.

Pyr. BB infusible; blackens, but becomes red again on cooling. With soda on charcoal is reduced, and then gives the reactions of native zinc. With borax usually reacts for manganese. Completely soluble in HCl and HNO_3 without effervescence.

Loc. Vegetable Creek, N.S.W., in cleavage plates.—Heazlewood, Tas., crystalline on quartz and siderite. Zincite is a frequent product of sublimation in iron and zinc smelting furnaces.

181. FRANKLINITE. Isometric; octahedral and cubical. Also granular and compact.

H 6. G 5. Lustre metallic. Colour iron black. Streak reddish brown. Opaque. Fracture conchoidal. Brittle. Slightly magnetic.

Comp. Oxide of zinc with proto-peroxide of iron and manganese $(Zn, Fe, Mn)O + (Fe_2, Mn_2)O_3$. Zinc 14 to 20 per cent.

Pyr. Infusible. With the fluxes reacts for manganese and iron. With soda on charcoal produces blue manganate of soda and a coating of zinc oxide.

Loc. Not hitherto observed in Australasia. Occurs in limestone with zincite and garnet at Franklin Furnace, New Jersey, U.S.A.—With calamite at Aix-la-Chapelle, Prussia. Has been artificially produced, but the crystals are white, or only coloured by ferric oxide.

182. SMITHSONITE (*Zinc Spar*). Hexagonal; six-sided prisms with pyramids; rhombohedra, scalenohedra. Faces of crystals often horizontally striated. Also botryoidal, globular, stalactitic, granular, and earthy. Cleavage rhombohedral perfect.

H 5. G 4·4. Lustre vitreous to pearly. Colour and streak white, sometimes coloured pale blue or green by carbonate of copper, or brown by oxide of iron. Transparent to translucent. Fracture uneven. Brittle.

Comp. Anhydrous carbonate of zinc, $ZnCO_3$. Zinc oxide 64·8 (metallic zinc 52), Carbon dioxide 35·2. Frequently with some iron, manganese, copper, lime, and magnesia.

Pyr. BB infusible, loses carbonic acid, and becomes opaque white. Moistened with cobalt solution and heated in OF becomes yellowish green. With soda on charcoal reduced to metal. Soluble with effervescence in HCl.

Loc. Generally occurs with sphalerite, of which it is a common decomposition product. Sphalerite on taking up oxygen is converted to $ZnSO_4 + 7\ H_2O$, which by the action of alkaline carbonates is changed to hydrous carbonate (hydrozincite) or anhydrous carbonate (smithsonite). On the other hand, alkaline silicates acting upon sulphate or carbonate of zinc produce silicate of zinc (calamite). Bowen, Q.—Common in the Broken Hill lode, crystallized in hexagonal prisms and scalenohedra, and frequently encrusting cerussite, psilomelane, native copper, and cuprite. Collington near Cooma, N.S.W.—Beltana, S.A.—Zeehan, Heazlewood, Tas.—New Zealand.

183. HYDROZINCITE (*Zinc Bloom*). Massive, stalactitic, encrusting, or earthy.

H 2. G 3·6. Dull white, sometimes coloured by carbonate of copper. Streak shining.

Comp. Hydrous carbonate of zinc, $Zn_3CO_5 + 2\ H_2O$.

Pyr. In closed tube loses water; otherwise like smithsonite.

Loc. In the gossan of the Broken Hill Lode, Barrier Range, with smithsonite, malachite, cerussite, and ferromanganese.

183*a*. AURICHALCITE. Acicular, laminar, plumose, encrusting.

H 2. G 3·5. Lustre vitreous. Colour pale green, bluish green. Translucent.

Comp. Cuprous hydrozincite, $(Zn_3, Cu_3)CO_6 + 2\ H_2O$; the ratio of zinc to copper is variable.

Pyr. With the fluxes gives copper reaction; otherwise like hydrozincite.

Loc. Occurs in the gossan of the Broken Hill Lode, Barrier Range, with ores of zinc, copper, lead, silver, and manganese.

184. CALAMITE (*Electric Calamine*). Rhombic; hemimorphous; usually six-sided prisms, terminating on one side in an obtuse rhombic pyramid, and on the other in a low truncated rectangular pyramid. Also botryoidal, stalactitic, fibrous, granular massive, vesicular. Cleavage prismatic perfect, basal indistinct.

H 5. G 3·2—3·9. Lustre of prismal faces vitreous, of basal planes pearly. Colour white, faintly bluish or greenish, brown; the colour due to metallic oxides. Streak uncoloured. Transparent, translucent, opaque. Strongly doubly refracting. Fracture uneven. Brittle. Pyro-electric.

Comp. Hydrous silicate of zinc, $Zn_2SiO_4 + H_2O$. Zinc oxide 66 (metallic zinc 53), Silica 25, Water 9. Frequently contains iron, carbonic acid, copper, lime, and alumina.

Pyr. F 6. Decrepitates. In closed tube loses water and becomes opaque white. With soda on charcoal is reduced, and gives a white coating of zinc oxide. Gelatinizes with HCl. Soluble in KHO.

Loc. Calamite is an alteration product chiefly of sphalerite or smithsonite. It occurs sparingly with other zinc ores in the localities mentioned under smithsonite.

PLATINUM GROUP.

185. NATIVE PLATINUM. Isometric; cube, octahedron. Crystals very rare, usually in rolled grains and nuggets.

H 4. G 16—19. Lustre metallic. Colour and streak greyish tin white, shining. Opaque. Ductile. Fracture hackly. Frequently polar magnetic.

Comp. Pt.; invariably contains iron, osmium, and iridium; frequently also copper, gold, palladium, rhodium. The proportion of platinum rarely exceeds 85 per cent. Samples from Fiefield, N.S.W., contain Pt 75·9, Os and Ir 10·6, Fe 10·1.

Pyr. BB infusible. Fine filings in the borax bead sometimes react for iron and copper; not otherwise affected by fluxes. Soluble in boiling aqua regia.

Loc. Platinum is generally associated with alluvial gold. The richest platinum drift deposits are those worked in the eastern part of the Government of Perm in Russia. The pay gravel yields from a fraction of a grain to half-an-ounce to the ton, and it depends on the amount of gold present whether the poorer sands can be profitably worked for platinum. The principal stream workings are situated on the eastern (Asiatic) slope of the Ural, but deposits are also met with on the western (European) side of the range, making it certain that the source of the platinum lies among the crystalline rocks and serpentine of the mountain chain. As a matter of fact, platinum has been detected along with chromite in serpentine, but so far no attempt has been made to win the metal from its matrix. Occurs at Fiefield, at the head-waters of the Bogan River, N.S.W., in the auriferous drift of a pliocene water-course lying at a depth of 70 feet below the surface. The country rock is Devonian sandstone and limestone resting upon Silurian slates, which are intersected by dykes of diorite. Several thousand ounces of platinum have already been raised on this field; the largest piece weighed five pennyweights.—Wiseman's Creek in auriferous alluvial; a nugget of platinum weighing nearly an ounce was found here.—In the gold-bearing sands of the Shoalhaven, Aberfoil, Sara, and Richmond Rivers. Ophir Bendemeer, Macleay district. At Mt. Darling Creek, eight miles east of Broken Hill, and at the Mulga Springs, fourteen miles north-east of Broken Hill, platinum occurs in an ochreous felspathic gangue, here and there stained by carbonate of copper. The rock, apparently a decomposed gneiss or mica schist, yields from a few grains to 30 dwt. of platinum to the ton, as well as some native gold. The platinum is in a state of such minute subdivision that the ordinary vanning process, adopted in the trials made to work the material on a large scale, has proved ineffectual.—Stockyard Creek, Foster, Vic.—Blue Tier, near Beaconsfield; St. Paul's River; Pieman River, Tas.—Southland, Riverton Beach, Foveaux Strait, Steward Island, N.Z.

Var. Platiniridium. H 6—7. G 23. Colour white. *Comp.* PlIr; Platinum 20—55, Iridium 28—77. Occurs with platinum in rolled grains which not rarely show cubic and octahedral faces.

186. IRIDOSMINE (*Osmiridium*). Hexagonal; six-sided prisms with replaced lateral edges. Crystals extremely rare; usually in flattened grains.

H 6·5. G 19—21. Lustre metallic. Colour tin white. Opaque. Difficultly malleable.

Comp. OsIr; Osmium 20—48, Iridium 43—77, usually with platinum, rhodium, ruthenium, iron, copper.

Pyr. BB infusible. Fusion with nitre in the closed tube liberates vapours of osmic acid which have an irritating odour. A strip of filter-paper steeped in indigo solution is discoloured by osmic acid. Placed on platinum foil and exposed first to the reducing and subsequently to the oxidizing action of the spirit flame imparts a conspicuous luminosity to the flame. Scarcely affected by boiling aqua regia.

Loc. Found in auriferous sands and gravels at Bingera, Mudgee, Bathurst, Aberfoil River, N.S.W.—Yarra gold workings; Stockyard Creek near Foster, Vic.—Castray River, Pieman River, King River, Dundas, Tas.

187. SPERRYLITE. Isometric; cube, octahedron, pentagonal and rhombic dodecahedra.

H 5. G 10·6. Lustre metallic, splendent. Colour steel grey. Opaque. Brittle.

Comp. Arsenide of platinum, $PtAs_2$. Platinum 52·5, Arsenic 46·6, Rhodium and Palladium 0·9.

Pyr. F 3. In closed tube unchanged. In the open tube emits arsenical vapours. Heated on platinum foil in OF until the arsenic is driven off leaves a spongy, lustrous, metallic residue. Insoluble in aqua regia.

Loc. Occurs in minute, well-defined crystals in the Canadian copper-mine, Sudbury, Ontario, Canada. It is the only known native salt of platinum.

IRON GROUP.

Iron, as present in its various natural compounds, is both geologically and geographically the most widely distributed of the heavy metals. It occurs in veins, zones of impregnation, and beds in rocks of every age and in nearly every part of the globe. The minerals of this group, with the exception of those in which the iron is already in the condition of proto-peroxide, become magnetic when heated in the presence of air. The borax glass in the oxidizing flame is yellow while hot, and colourless when cold. (The saturated bead is red, hot, and yellow, cold.) If manganese is present it is blood red while hot, and brownish yellow when cold. In the reducing flame it is greyish green (bottle green) both hot and cold; with the addition of chloride of tin it is vitriol green. The micro. salt glass in the oxidizing flame is brownish red while hot, on cooling becomes yellow, then green, and finally, when cold, colourless, if not too highly saturated. In the reducing flame the same reactions take place, but the colours are somewhat paler. All the minerals of the group are soluble in acids; from the solutions a precipitate of hydrous ferric oxide separates on the addition of ammonia.

188. NATIVE IRON. Isometric; octahedron. Also crystalline granular and massive. Cleavage octahedral.

H 4·5. G 7·5—7·8. Lustre metallic. Colour iron grey. Streak shining. Fracture hackly. Malleable, ductile. Strongly attracted by the magnet.

Comp. Fe; contains, however, rarely more than 90 per cent. of iron, the rest being nickel, cobalt, copper, and other metals.

Pyr. See general observations under "Iron Group."

Loc. On account of its great liability to oxidation metallic iron only occurs in nature under exceptional conditions. It has been observed as a constituent of basalt in Greenland, the north of Ireland, Auvergne in France. The larger masses that have been discovered in various parts of the globe have invariably proved to be of meteoric origin, and always contain nickel or cobalt. Iron meteorites ("siderites") have been found at Deniliquin, Bingera, Gilgoin near Brewarrina, N.S.W.—Cranbourne, Vic., several blocks, the largest weighing some four tons.—Gawler Ranges, S.A.—Blue Tier, North-eastern Tas.—East of York, W.A.—Makariwa near Invergargill, N.Z.

Var. Awaruite. H 5. G 8·1. *Comp.* $FeNi_2$; Iron 31, Nickel 68, with traces of cobalt, sulphur, and silica. Occurs in the form of grains in company of gold, platinum, chromite, and magnetite in gravel drift in the Gorge River, Awarua Bay, west coast of Middle Island, New Zealand; surmised to be derived from the disintegration of peridotite or serpentine.

189. PYRITE (*Iron Pyrites, Mundic*). Isometric; cube, octahedron, pentagonal dodecahedron. Faces of the cube striated, the lines on one face being right-angled to those on adjoining faces. Crystals sometimes elongated, tending to produce fibrous structure. Also botryoidal, concretionary, encrusting, compact. Cleavage octahedral and cubic indistinct.

H 6·5. G 4·9—5·2. Lustre metallic, splendent. Colour brass yellow, tarnishing to golden yellow. Streak greenish or brownish black. Opaque. Fracture uneven. Brittle. Emits sparks when struck with steel.

Comp. Iron bisulphide, FeS_2. Iron 46·7, Sulphur 53·3; frequently with small proportions of copper, gold, silver, nickel, cobalt, etc.

Pyr. BB fuses at 1 to a black, shining, magnetic globule. In the closed tube and on charcoal gives sulphurous vapours.

Loc. Pyrite is the most common ore in mineral veins of all kinds, and not rarely forms independent deposits: veins, seams, beds, or irregular masses. It frequently enters into the composition of granite, greenstone, crystalline schists, and is a common accessory in argillaceous rocks—clays, shales, slates, marls. Frequently accompanies coal and lignite seams; less common in arenaceous rocks. It occurs abundantly in Australian gold-fields, where it is as a rule auriferous and argentiferous, yielding from 1 to 200 oz. of gold, and from 1 to 40 oz. of silver to the ton. As a secondary product it arises from the action of alkaline sulphides (or sulphuretted hydrogen) upon aqueous solutions of carbonate, sulphate, or hydrous oxide of iron. Pyrite oxidizes more difficultly than marcasite; on decomposition both yield $FeSO_4 + 7\ H_2O$ (melanterite); on further oxidation $2\ Fe_2O_3\ 5\ SO_3 + 18\ H_2O$ (copiapite). Since it contains two atoms of sulphur to one of iron there is a surplus of SO_3, which either combines with other bases to sulphates, or passes into the ground-water, as shown by the frequent presence of free sulphuric acid in spring and mine waters. Sometimes the sulphur remains behind in the native condition, or is changed into H_2S. The alteration of ferric sulphate is usually into limonite, more rarely into hematite. Pseudomorphs of limonite after pyrite and marcasite are accordingly of frequent occurrence. Organic matter again reduces ferrous sulphate to pyrite (oftener perhaps to marcasite), as may be observed in the recent deposition of sulphide of iron on mine timber. In the deep leads of Ballarat, Creswick, and elsewhere, trunks of sub-fossil conifer trees are found partially or wholly converted into pyrite or marcasite, which often contain an appreciable proportion of gold. Not rarely pyrite constitutes the petrifying medium of shells, especially when enclosed in clay, marl, or shale. Pyrite is often superficially altered to marcasite; occasionally complete paramorphs of marcasite after pyrite have been observed.

190. Marcasite (*White Iron Pyrites*). Rhombic; hexagonal tables; macles with re-entering angles resembling spear-heads (*Spear Pyrites*); flattened in divergent groups (*Cockscomb Pyrites*). Also radiated fibrous (*Radiated Pyrites*); hair-like aggregates (*Capillary Pyrites*). Nodular, reniform, granular, massive. Cleavage prismatic distinct.

H 6. G 4·7. Lustre metallic. Colour bronze yellow, greenish or greyish yellow. Streak greenish or brownish black. Fracture uneven. Brittle.

Comp. and *Pyr.* Like pyrite.

Loc. Marcasite is perhaps always a secondary product, and formed in the wet way in the manner described under pyrite (*q. v.*). It oxidizes more readily than pyrite, and specimens, even when kept in a dry cabinet, are very liable to decompose into ferrous sulphate. Like pyrite it is frequently auriferous. Tinaroo, Bowen, Ethridge, Charleston, Q.—Carcoar, Cadia, Forest Reefs, Reedy Creek, Shoalhaven River, N.S.W.—Common in sub-basaltic gravel drift at Ballarat, Creswick, Beaufort, etc., occurring in reniform masses with radiating structure; frequently replacing the substance of conifer trunks embedded in the drift. Lal Lal, in lignite. In the Madame Berry Mine, Smeaton, it constitutes the cementing medium of an auriferous quartz pebble conglomerate. In small globules and botryoidal coatings on quartz, Dalzell Mine, Ballarat East.—Waukaringa, S.A.—In coal and lignite, Mersey and Don rivers, Beaconsfield, Tas.

191. PYRRHOTITE (*Magnetic Pyrites*). Hexagonal; six-sided tabular prisms terminating in low truncated pyramids. Crystals rare; commonly granular massive. Perfect basal cleavage.

H 4. G 4·5. Lustre metallic. Colour bronze yellow to red brown, easily tarnished on exposure. Streak iron black. Brittle. Attracted by the magnet.

Comp. Monosulphide of iron, FeS; varying from Fe_6S_7 to $Fe_{11}S_{12}$. Iron 60 to 61·6, Sulphur 40 to 38·4. Frequently contains nickel, manganese, gold, or silver. Niccoliferous varieties pass into pentlandite.

Pyr. F 1. In the closed tube gives no sulphur. In the open tube and on charcoal yields sulphurous vapours. After roasting on charcoal leaves a non-magnetic, or but slightly magnetic, residue of oxide of iron, which with fluxes or in the nitric solution generally reacts for nickel.

Loc. Pyrrhotite affects chiefly hornblendic rocks, forming not rarely an accessory constituent of amphibolite, diorite, syenite, etc. Also occurs in metalliferous veins. On the gold-fields it is frequently, though not abundantly, met with in quartz veins, associated with pyrite, sphalerite, and arsenopyrite, and, like them, is usually auriferous. Charters Towers, Ravenswood, Q.—Emmaville, Vegetable Creek, Pye's Creek, N.S.W. At the Pinnacles, Barrier Range, it occurs abundantly with leucopyrite (both niccoliferous), galena, and garnet in amphibole rock.—Maldon, in auriferous quartz veins, as well as in the bordering metamorphic sandstone. Band and Albion Mine, Ballarat. Wood's Point, Howqua, Vic.—Mt. Ramsay, with bismuth in amphibole rock. Mt. Bischoff, Dundas, Penguin, Beaconsfield, Tas.—Dusky Sound, Otago; Thames, Nelson, N.Z.

192. ARSENOPYRITE (*Arsenical Pyrites, Mispickel*). Rhombic; modified four-sided prisms, terminating in domes. Also columnar, divergent, granular, or massive. Cleavage prismatic imperfect.

H 6. G 6—6·4. Lustre metallic. Colour tin white to steel grey. Streak iron black. Fracture uneven. Brittle.

Comp. Sulpharsenide of iron, $FeS_2 + FeAs_2$. Iron 34·4, Arsenic 46, Sulphur 19·6. Frequently contains gold, silver, bismuth, nickel, cobalt, manganese.

Pyr. BB fuses at 2. On charcoal emits arsenical fumes, afterwards sulphurous vapour. Covers the charcoal at some distance from the assay with a white, easily volatile, sublimate of arsenous acid. After complete roasting leaves a black magnetic globule. In the closed tube gives a sublimate of sulphide of arsenic, which is dark red brown to black while hot, and orange red when cold, and near the assay a mirror of metallic arsenic.

Loc. Occurs in mineral veins associated with pyrite, sphalerite, galena, and ores of silver, gold, tin, etc. Sometimes forms an ingredient in sandstone, crystalline schists, and serpentine. Hodgkinson, Ravenswood, Charters Towers, Norton, Chowey Creek, in gold veins. Tinaroo and Stanthorpe with tin. Mt. Shamrock with gold and bismuth, Q.—Fairfield, Emmaville, Glen Innes, Armidale, Oberon, Lucknow, Gulgong, Peelwood. At Nambucca River, N.S.W., occurs finely crystallized in rhombic prisms with brachydomes, and contains at the rate of 28 oz. of gold to the ton.—Common in the auriferous quartz veins of Ballarat, Bendigo, Maldon, Broadford, Doon, Walhalla, Wood's Point, Vic., often entering the sandstone and slate for some distance from the lodes.—Forest Range near Adelaide, Glen Bar and Talisker Mines, Woodside, Manna Hill, Waitpinga, S.A., in gold veins.—Mt. Ramsay, gold and silver bearing with bismuth in amphibolite. Mt. Bischoff and Pieman River, stanniferous. Beaconsfield, Penguin, Heemskirk, Pelion, Tas. Reported cobaltiferous from southern slope of Mt. Wellington, near Hobart.

193. LÖLLINGITE (*Leucopyrite*). Rhombic; crystals like arsenopyrite. Also granular massive.

H 5—5·5. G 7—8·7. Lustre metallic. Colour tin white to greyish white. Streak iron black. Fracture uneven. Brittle.

Comp. Arsenide of iron, $FeAs_2$ to Fe_2As_3. Iron 27·2 to 33·2, Arsenic 72·8 to 66·8. Often with traces of sulphur, some varieties passing into arsenopyrite. Frequently also contains cobalt, nickel, bismuth, antimony, copper.

Pyr. F 3—4. In closed tube yields a sublimate of metallic arsenic. On charcoal gives arsenical fumes and a magnetic globule.

Loc. Lady Bevy's Mine, Pinnacles, Barrier Range, N.S.W., niccoliferous, with pyrrhotite in amphibole rock.

194. MAGNETITE (*Magnetic Iron Ore*). Isometric; octahedron and dodecahedron. Sometimes exhibits under the microscope dendritic forms. Also granular massive, and in rolled grains; sometimes powdery. Cleavage octahedral distinct.

H 6. G 4·9—5·2. Lustre metallic to sub-metallic. Colour and streak iron black. Under the microscope it is perfectly opaque, and by transmitted light has a bluish-black metallic lustre. Sections usually present square, rectangular, or triangular outlines. In basalt and other basic eruptive rocks the magnetite grains are frequently grouped in regular zones around the larger crystals of hornblende, augite, felspar, and mica. Fracture sub-conchoidal, shining. Brittle. Strongly magnetic.

Comp. Proto-peroxide of iron, $FeO, Fe_2O_3 = Fe_3O_4$. Iron 72·4, Oxygen 27·6. Some varieties contain oxide of manganese and titanium.

Pyr. F 5—6. After prolonged heating in OF becomes non-magnetic. With soda on charcoal it is reduced; the metallic spicules sink into the coal, from which they may be freed by elutriation in the agate mortar. Slowly but completely soluble in HCl; in the solution NH_3 throws down a flocculent precipitate of ferrous hydrate.

Loc. Magnetite is one of the most widely distributed minerals, occurring (1) as a primary constituent (essential or accessory) in granite, greenstone, volcanic rocks, serpentine, crystalline schists, corundum, etc.; (2) as a secondary product, forming beds or veins, frequently resulting from the decomposition of amphibole; (3) in the form of washed grains in detrital deposits, in tin- and gold-drifts, in river and sea-sands, often derived from the disintegration of basalt or diabase. Mt. Leviathan, Cloncurry River, in massive beds. Mt. Biggenden, in compact masses and druses of fine crystals, associated with bismuth and gold-bearing amphibolite. With pyrite in quartzite at Mt. Morgan, Q.—Wallerawang, in seams at the base of the coal-measures, where these rest upon Silurian strata. Mt. Lambie, Mt. Wingen, Grafton, Solferino, Belubula Creek near Bathurst. Pinnacles; Barrier Range, forming the caps of syenite dykes. In granite, Jinjellic, N.S.W.—As an essential constituent of basalt in all the volcanic districts of Victoria.—Yalka Flat, Mt. Cone; Mingary, in granite; Wells Creek, in protogene. Mt. Lofty Range, Aldinga, Teetulpa, Yudanamutana, Musgrave and Macdonnell Ranges, S.A.—Massive with pyrite, chalcopyrite, and quartz, Penguin. Lempuire, Hampshire Hills, Emu River, Blythe River, Ilfracombe, Mt. Pelion, Tas.—Abundant in granite, diorite, and schist country in many parts of W.A. —Fox Glacier, Canterbury. Dusky Sound, Otago. Ruatangata. On the shore of Taranaki, iron-sand derived from the disintegration of trachyte.—Balade nickel-mine, New Caledonia, in chlorite schist and serpentine.

195. Hematite. Hexagonal; rhombohedron, scalenohedron, hexagonal pyramid, broad tabular prisms. Also columnar, fibrous, laminar, reniform, stalactitic, granular, compact, earthy. Cleavage rhombohedral and basal imperfect.

H 6. G 4·2—5·3. Lustre metallic, splendent to dull. Colour iron black; in earthy varieties cochineal red. Streak cherry red. Opaque; laminar varieties translucent. Fracture sub-conchoidal, uneven, earthy.

Comp. Sesquioxide of iron, Fe_2O_3. Iron 70, Oxygen

30; occasionally with magnesia and titanic oxide. Some impure varieties contain an admixture of magnetite, and then are more or less magnetic.

Pyr. Infusible. In RF becomes magnetic. Otherwise like magnetite.

Loc. and *Var.* (*a*) *Specular Iron;* crystallized, usually in rhombohedra. Perfect metallic lustre. Under the microscope like magnetite, except that the sections of crystals are hexagonal or, when transverse, appear in narrow, parallel-sided laths. Occurs as an independent rock; frequently replaces mica in granite, gneiss, and porphyrite. Occasionally takes the place of magnetite in basalt.

Normanton, with limonite and malachite, Mackay, Q.—Carwary, Shoalhaven, Carcoar. In Hawkesbury sandstone near Sydney. Massive in quartz, O'Connell's Plains, Bathurst, N.S.W.—In dolerite, Malmsbury and Ballarat; in auriferous quartz veins, Mt. Korong, Maldon; forming seams in quartz, east of Lancefield, Vic.—Flinders Island, in basalt. Black Bluff, Arthur River, Meredith Range, Ilfracombe, Tas.

(*b*) *Micaceous Iron;* foliated, in crystalline plates and scales, which under the microscope are translucent and of a cochineal-red or reddish-yellow colour. Under crossed nicols opaque; by reflected light shows chatoyant colours and strong metallic lustre. Occurs in quartz veins, felsite porphyry, volcanic rocks, and serpentine.

Mt. Eurie, head of Dugald River, Q.—Boro, Yass, Tumut, Delegate, Grove Creek, Abercrombie River, and in numerous places in New England, N.S.W.—Rose's Gap near Stawell; Lake Tyers, Tambo, Vic.—Eurelia, Angaston, Gawler, Burra, Teetulpa, in quartz. In siliceous tuff and in gypsum, Clare, S.A.—Mt. Lyell, Whyte River, Pieman, Mt. Heemskirk, Tas.—Gascoyne, W.A.

(*c*) *Red Hematite;* reniform ("kidney iron ore"), stalactitic with fibrous structure; pseudomorphous, particularly after pyrite and siderite. Lustre sub-metallic. Occurs in independent beds and metalliferous veins.

Herberton; Cloncurry River near Mt. Leviathan, with magnetite; between the head of the Dugald River and the Leichhardt, Q. Fibrous, Grampians, Vic.—Port Lincoln, Point Ogilistos, Leigh's Creek, Wallaroo; fibrous, Angaston; massive, Yudanamutana, S.A. Massive, partly magnetite, Penguin; King Island, Blythe River, Mt. Lyell, Dial Range, Tas.—Victoria district, Northampton, W.A.—Richwood, Mongonui, Auckland, N.Z.

(*d*) *Red Ochre;* earthy. Masses of hematite often present at their outcrop a weathered appearance, the mineral is changed to a soft clayey substance (*reddle*), which contains usually some silica, phosphoric acid, and water, without however becoming limonite.

Grafton, N.S.W.—Elaine; Western Port, in conjunction with basalt.—Peake, Bugle Range, Manna Hill; Burrundie, Northern Territory, S.A.—Mt. Lyell, West Tamar, Flinders Island, Tas.

Hematite becomes, through loss of oxygen and without taking up water, converted into magnetite, thus $3\ Fe_2O_3 - O = 2\ Fe_3O_4$ (100 parts of hematite furnishing 96·66 parts of magnetite). On the other hand, magnetite is through access of oxygen altered to hematite (100 parts of magnetite producing 103·45 parts of hematite). In the presence of water the alteration is to limonite. On incomplete decomposition mixtures of magnetite and hematite, or of magnetite and limonite, are formed.

196. GOETHITE. Rhombic; prisms with planes of domes and pyramids. Prismal faces vertically striated. Mostly acicular, fibrous, foliated, reniform, massive. Cleavage brachydiagonal very perfect.

H 5. G 4—4·4. Lustre vitreous. Colour brown, yellowish, reddish, blackish. Streak brownish yellow.

Comp. Hydrous sesquioxide of iron, $Fe_2O_3H_2O = H_2(Fe_2)O_4$. Iron 62·9, Oxygen 27, Water 10·1. Generally with some manganese and phosphoric acid.

Pyr. BB infusible. In RF becomes black and magnetic. In closed tube yields water. Difficultly soluble in HCl.

Loc. In the gossan of metalliferous veins. Mt. Morgan, Stradbroke Island, Pine Mountains, Q.—Berrima, Wallerawang, Lithgow; Carwell, pseudomorphous after pyrite; Manley Beach near Sydney, granular in Triassic sandstone; Illawarra district, N.S.W. In auriferous quartz veins, Ballarat, Castlemaine, Vic.—Ediacara, acicular; Port Augusta, S.A.—Penguin, Emu Bay, Pieman, Dundas, Blythe River, Tas.

197. Limonite (*Brown Hematite*). Amorphous; pseudomorphous; stalactitic, concretionary, sub-fibrous, compact, earthy.

H 5. G 3·6—4. Lustre sub-metallic, silky, dull. Colour brown, yellow, black. Streak yellowish brown.

Comp. Hydrous sesquioxide of iron, $2\ Fe_2O_3\ 3\ H_2O = H_6(Fe_2)_2O_9$. Iron 59·9, Oxygen 25·7, Water 14·4. Usually with some oxide of manganese, phosphoric acid, alumina, lime, silica, and additional water, these impurities amounting to rarely less than 10, and sometimes exceeding 25 per cent.

Pyr. Like goethite.

Loc. and *Var.* Limonite is always a product of the alteration of other iron ores or ferriferous minerals. It occurs pseudomorphous after pyrite at Kilkivan, Q. Broken Hill, N.S.W. White Horse Range, Ballarat. Mt. Bryant; Yerlina Creek, Flinders Range; Teetulpa, S.A. Beaconsfield, Tas.—After galena at Silverton, N.S.W.—After siderite at the Australian Broken Hill Mine, Barrier Range, and Dundas, Tas.

Limonite is the most abundant as well as, geographically and geologically, the most widely distributed of the iron ores. It occurs in beds and irregular deposits with sediments of every age, but more especially those of recent formation. It frequently results from the decomposition of basalt; it constitutes the bulk of the gossan of metalliferous veins, and the cementing medium of auriferous quartz conglomerate and breccia on some of the gold-fields. *Arenaceous limonite* occupies extensive tertiary fossiliferous beds, exposed in many parts of the south coast of Australia, and often enclosing nodular and stalactitic concretions of pure limonite. It occurs as *bog iron ore* in the beds and along the margins of swampy depressions, particularly in basalt country; as *pisolitic iron ore* in the form of pea- and bean-shaped concretions strewn over the surface, or embedded in the soil of volcanic tracts; as *oolitic iron ore* in the form of small, often hollow, spherical concretions cemented by amorphous ferric hydrate; as *stilpnosiderite*, forming a thin, black, varnish-like coating with botryoidal surface on ordinary limonite or psilomelane. In its earthy condition it is called *yellow ochre*. Ravenswood, Charters Towers, Ipswich, Warwick, Mt. Morgan; stilpnosiderite at Cloncurry, Q.—Massive, compact or spongy in most of the metalliferous districts of New South Wales; oolitic at Pooncarie, Darling River; stilpnosiderite on stalactitic psilomelane, Broken Hill. Much of the "black band" associated with the coal-measures of N.S.W. is limonite.—Moorabool River near Lal Lal, on the denuded edge of a flow of basaltic lava; Illabarook; Mt. Major near Benalla; Mordialloc, Western Port. Auriferous at Enfield, Carngham, Ararat, Bendigo, Taradale, Vic.—Port Pirie, Rapid Bay, Port Augusta, Yorke's Peninsula, Angaston, Hindmarsh Valley, Lake Eyre district, Port Darwin district. Auriferous at Echinga, Manna Hill, Teetulpa, S.A.—Ilfracombe; chromiferous at Georgetown, Tamar, Tas.—Abounds in most of the mineral districts of Western Australia.—Thames, Nelson, Auckland, N.Z.

198. MENACCANITE (*Titanic Iron*). Hexagonal; isomorphous with specular iron; six-sided tabular prisms with vertical edges replaced by faces of the rhombohedron. Usually granular or in cleavage plates; also in rounded grains. Cleavage basal distinct.

H 5·5. G 4·5—5. Lustre sub-metallic. Colour bluish black. Streak shining reddish brown to brownish black.

Opaque. Fracture conchoidal. Some varieties are slightly magnetic.

Comp. Titanate of iron with sesquioxide of iron (titaniferous hematite), $FeTiO_3 + n(Fe_2)O_3$, the ratio of iron and titanium being variable. Usually contains about 25 per cent. of titanium; the variety *Ilmenite* contains from 26 to 30 per cent. of titanium. Most varieties also contain manganese, chromium, magnesia, and lime.

Pyr. BB infusible, or fusible at 6. Becomes magnetic. With soda on charcoal yields a yellow crystalline glass which turns greyish white on cooling. The micro. salt bead is yellow hot, colourless cold in OF; and yellow hot, violet cold in RF. In the presence of much iron the violet colour becomes only apparent after treatment with chloride of tin in OF, otherwise the bead is brownish red. Slowly decomposed by acids with separation of titanic oxide. Fused with soda dissolves in HCl; the solution boiled with tinfoil acquires a blue or violet colour.

Loc. Titaniferous iron is frequently a constituent of volcanic rocks, granite, crystalline schists and granite, and is generally found in loose grains in the detritus derived from these rocks, *e.g.* in tin- and gold-drifts, usually associated with gem-stones. Being a regular constituent of certain volcanic rocks, it is often found in rolled grains in the watercourses of basaltic country. Stanthorpe, in tin wash; Canoona, Rockhampton, in serpentine; Burnett district, with gold in gem-sand. In basaltic detritus, Darling Downs, Q. —In auriferous sands, Bingera, Mudgee, Ophir, Bathurst, Uralla, Glen Innes, Cudgegong, Wagga. In quartz veins at Wellington.—In gold-drift at Ballarat, Talbot, Castlemaine, Ararat, and other Victorian gold-fields. In gem-sand, Berwick, Packenham, Leongatha, Tylden. In basalt country, Smeaton, Campbell's Creek near Castlemaine, Merino, Merton, Euroa, Western Port, Vic.—Benowrie, Cornflower Hill, S.A. —Franklin Harbour, George's Bay, Blue Tier, Ringarooma, Blythe River, Tas.—South of Perth, W.A.—Hokitika, N.Z.

199. ISERITE (*Titanic Iron*). Isometric; octahedral, cubic. No cleavage; generally in loose washed grains.

H 5·5. G 4·8. Lustre sub-metallic. Colour black, bluish black. Strongly magnetic.

Comp. Like menaccanite, with 20 per cent. of titanium.

Pyr. Like menaccanite, from which it is distinguished by its crystal form, want of cleavage, and magnetic property.

Loc. Commonly found in the detritus of basalt. Mouth of Clarence River, N.S.W.—Lake Burrumbeet, Rose's Gap, north of Stawell, Vic.; and in many of the localities mentioned under menaccanite.

200. CHROMITE (*Chromic Iron*). Isometric; octahedral; mostly granular, massive, compact. Not distinguishable from magnetite except chemically.

H 5·5. G 4·4. Lustre sub-metallic. Colour iron black. Streak brown. Opaque. Fracture uneven. Brittle. Some varieties are magnetic from admixture of magnetite.

Comp. Chromic iron with some magnesia and alumina, $(Fe, Mg, Cr)O + (Cr_2Al_2Fe_2)O_3$. Oxide of iron 20 to 36, oxide of chromium 40 to 64.

Pyr. BB infusible or fusible at 6; becomes magnetic. The borax and micro. salt beads are emerald green in both flames. The reaction is best obtained by previously fusing the assay with soda on charcoal in order to reduce the iron; a green-coloured slag remains which being free from iron gives a pure chrome colour to the borax or micro. salt bead. In the wet way chromic oxide may be determined in the following manner. The assay is fused with 2 parts of soda and 2 parts of nitre, and the fusion dissolved in water. To the decanted fluid add acetic acid; boil and decant; add a crystal of acetate of lead, and stir: yellow chromate of lead will precipitate.

Loc. Occurs in veins and bedded masses, usually in connection with serpentine and other magnesian silicates; also disseminated in eruptive and metamorphic rocks. Brisbane River near Ipswich; Mt. Wheeler near Rockhampton, Q.—

Woolomi near Tamworth, forming a vein-like body forty feet in thickness, associated with serpentine, diallage rock, and black slate. Bland near Young; Hanging Rock, Nundle, Stony Batta, Bendemeer, in serpentine. In rolled pebbles at Bingera, Mudgee, Yass, Horton River, Sandon near Armidale. In diallage rock, blocks of which are embedded in basalt, at the Pennant Hills Quarry near Paramatta, N.S.W.—Heathcote, well crystallized, disseminated in quartz, and loose in detritus. Strathloddon, Gippsland, Vic.—Whyte River, Heazlewood, Meredith Range, Pieman River, Dundas, Tas.—Whangamoa, Aniseed Valley, and Dun Mountains, Nelson, N.Z. In the last-mentioned locality it occurs finely disseminated in olivine rock (dunite), and also in veins up to twelve feet in thickness.—New Caledonia, massive in serpentine; concretionary in nickel ore, and in rolled pebbles in the alluvial. The rolled fragments are richest in chromic oxide (66·5 per cent.), owing to the iron being largely replaced by magnesia (12—16 per cent.).

201. SIDERITE (*Chalybite, Sparry Iron Ore*). Hexagonal; rhombohedron with faces often curved; more rarely scalenohedron, prism, and pyramid. Also crystalline granular, botryoidal, sometimes fibrous. Cleavage rhombohedral perfect.

H 4. G 3·8. Lustre vitreous to pearly. Colour yellowish white, grey, brown. Darkens on exposure. Translucent. Fracture uneven, brittle.

Comp. Carbonate of iron, $FeCO_3$. Iron 48·3, Oxygen 13·8, Carbon dioxide 37·9, generally with some protoxide of manganese, lime, and magnesia.

Pyr. F 4·5—6. Decrepitates. In closed tube loses carbonic acid, blackens, and becomes magnetic. Completely soluble with effervescence in HCl. In the solution NH_3 throws down ferric hydrate, oxalate of ammonia precipitates the lime, and phosphate of soda the magnesia that may be present. Fusion with soda generally produces a greenish-blue mass of manganate of soda.

Loc. Siderite occurs in beds and veins in crystalline schists, generally associated with iron and copper pyrites, galena, sphalerite, brownspar, calcite, quartz. Cloncurry, Mt. Biggenden, Q.—Gulgong; Newstead Mine, New England; O'Connell's Plains, Westmoreland. Forms the gangue of galena veins at Umberumberka, Barrier Range, N.S.W.—With auriferous copper pyrites, Maldon; with chalcopyrite and galena, St. Arnaud, Vic.—In auriferous quartz veins Teetulpa. With chalcopyrite at Mt. Lyndhurst and Oratunga copper-mine. Barossa, Mt. Lofty. With galena at Ediacara, S.A.—In lead veins at Dundas, Zeehan, Heazlewood, Whyte River, Mt. Bischoff, Brown's Plains, Pieman River, Tas.

Var. Spherosiderite occurs in botryoidal, mammillary, and spherical concretions, often with the concentric layers of different colours, like agate. Generally contains much lime, and chiefly affects basalt and other rocks rich in iron and lime felspar. Toowoomba, Q.—Inverell, Rocky Ridge, N.S.W. At the Pinnacles Tribute Mine, Barrier Range, galena is sometimes coated with secondary quartz, which in turn is covered by spherosiderite, and this again is invested by pyrite.—Common in the basalt of Richmond near Melbourne, Geelong, Ballarat, Vaughan, Daylesford, Ballan, Vic.

Black Band; compact to earthy. Contains much carbonaceous and argillaceous matter (*clay ironstone*). Occurs in layers intercalated with the coal-seams and shales of the coal-measures. Jamberoo, Woolongong, N.S.W.—Collingwood coal-mine, Nelson, N.Z.

202. TANTALITE. Rhombic; six-sided prism terminating in truncated domes; commonly twinned, the plane of composition parallel to the brachypinacoid. Also granular massive. Cleavage macrodiagonal perfect.

H 6. G 5·5—7·5. Lustre sub-metallic, brilliant. Colour greyish black to brownish black. Streak dark red to black. Opaque; brittle.

Comp. Tantalate of iron, $FeTa_2O_6$. Oxide of iron 24·8 (metallic iron 19·1), Tantalic acid 75·2. Part of the iron frequently replaced by manganese (*mangano-tantalite*), sometimes by tin (*cassitero-tantalite*), and part of the tantalic acid by niobic and tungstic acids, when it graduates into columbite.

Pyr. Infusible. In the borax glass gives reaction for iron (frequently also for manganese and wolfram). In RF becomes greyish white by flaming. Treated in the wet way generally gives the reaction of niobic acid (*vide* Columbite).

Loc. Tantalite appears to be restricted to plagioclase granite, in which it occurs either disseminated or aggregated on joints; usually associated with wolfram, schorl, and beryl. Maldon, Vic., in the felspar of a pegmatite vein in granite.

203. COLUMBITE (*Niobite*). Rhombic; crystals like tantalite. Cleavage macrodiagonal distinct.

H 6. G 5·5—6·5. Lustre sub-metallic. Colour greyish black, brownish black; usually with an iridescent tarnish. Streak red brown to black. Opaque. Fracture sub-conchoidal. Brittle.

Comp. Niobo-tantalate of iron, $FeNb_2O_6 + Fe_2Ta_2O_6$, variable. Niobic acid 48 to 66, Tantalic acid 12 to 36. Usually with manganese and tungsten. A variety containing from 4 to 5 per cent. of protoxide of manganese has been named *Dianite*.

Pyr. Infusible. With fluxes reacts for iron, and usually also for manganese and tungsten. Fused with potassium bisulphate and washed in dilute HCl, the residue treated with strong HCl and H_2SO_4, with the addition of a fragment of metallic zinc, produce a blue solution which gradually becomes brown (Nb_2O). Dianite, which gives also the reaction of wolfram (*q. v.*), should be previously digested in aqua regia in order to remove the tungsten.

Loc. Occurs in granite, usually associated with wolfram, schorl, cassiterite, and plagioclastic felspar. Walsh River, Hodgkinson Gold-field, Q., dianite iridescent in tabular, cleaved masses with wolfram and quartz.—Rhombic plates in quartz, Gippsland, Vic.—Barossa near Gawler, S.A., in loose, flattened grains.

204. VIVIANITE (*Blue Iron Earth*). Monoclinic; narrow prisms terminating in domes or octahedra. Often radiating aggregates of acicular crystals. Also nodular, encrusting, divergent fibrous, earthy. Cleavage clinodiagonal highly perfect.

H 2. G 2·6. Lustre vitreous, on cleavage planes pearly, sub-metallic. When fresh colourless or white, speedily oxidizes to a sea-green tint, which gradually deepens to indigo blue and greyish blue. Streak uncoloured or light blue. Transparent, on exposure translucent to opaque. Cleavage plates flexible. Sectile.

Comp. Hydrous phosphate of iron, $Fe_3P_2O_8 + 8\ H_2O$. Protoxide of iron 43 (metallic iron 33·4), Phosphoric acid 28·3, Water 28·7.

Pyr. BB fuses at 1·5 to a black magnetic globule, colouring the flame pale green (P_2O_5). In the closed tube yields much water. With borax gives iron reaction. If the powder is fused in the closed tube with a fragment of metallic sodium or magnesium the phosphoric acid is reduced; the fused mass, when cold, moistened with a drop of water gives off phosphoretted hydrogen, recognizable by its pungent odour. The cold nitric solution gives with molybdate of ammonia a yellow precipitate. The powder blackens in KHO.

Loc. Occurs with pyrite and chalcopyrite in quartz veins, slate, and sandstone; also in clay, marl, tuff, and sand. Nymagee, with copper pyrites; Boorook, in sandstone; in granite at Timbarra, N.S.W.—In cave under the falls of the Wannon River at Redruth, Vic., splendid crystals two or three inches in length, embedded in soft, white volcanic tuff. Charlotte Plains, Moolort, partly altered to siderite, forming veins in soft Silurian slate underlying auriferous drift, beneath sixty-five feet of basalt. Impregnating quartz, and colouring it a fine smalt blue at Maldon. Nodular masses in sub-basaltic gold-drift at Corinella near Daylesford and Ararat. In sandstone at Sarsfield, Buckland, and Bairnsdale, Vic.—Angaston, Strathalbyn, Rowlands Creek, S.A.—Mt. Bischoff, Pieman River, Waterhouse, Tas.—Pohangina River, Manawatu, N.Z.

205. SCORODITE. Rhombic; eight-sided prisms terminating in four-sided pyramids. Also encrusting and pulverulent. Cleavage prismatic imperfect.

H 3—4. G 3·2. Lustre vitreous, resinous, dull. Colour leek green, yellowish, brown. Streak uncoloured. Transparent to translucent. Fracture uneven.

Comp. Hydrous arseniate of iron, $(Fe_2)As_2O_8 + H_2O$. Peroxide of iron 34·7 (metallic iron 24·3), Arsenic acid 49·8, Water 15·5. *Arseniosiderite* contains from 8 to 12 per cent. of lime.

Pyr. F 1, colouring the flame blue. On charcoal gives arsenical odour, and fuses to a black magnetic globule. In the closed tube yields water. With borax reacts for iron. The powder becomes reddish brown in KHO.

Loc. Usually associated with arsenopyrite, of which it is a decomposition product. Star silver-mine, Mt. Albion. Mt. Biggenden, Q.—Peelwood; Cadell's Reef near Mudgee; Louisa Creek, Wellington, N.S.W.—In auriferous quartz veins, Abe Lincoln Reef, Crooked River; Beehive Reef, Maldon; Blucher's Reef, Maryborough; Merton Creek, Doon; Dry Creek, Strathbogie Ranges, Bethanga, Vic.—Woodside, Teetulpa, S.A.—Mt. Bischoff, Emu River, Waterhouse, Mt. Pelion, Scamander River, Tas.

206. PHARMACOSIDERITE (*Cube Ore*). Isometric; cube with alternate angles replaced by planes of the octahedron or tetrahedron. Crystals always small. Also crystalline granular. Cleavage cubic imperfect. Planes of the cube sometimes diagonally striated.

H 2·5. G 3. Lustre vitreous to resinous. Colour olive green, grass green, yellowish to reddish brown. Streak paler than the colour. Translucent. Sectile. Pyro-electric.

Comp. Hydrous phosphato-arseniate of iron $3(Fe_2)As_2O_8+H_6(Fe_2)O_6+12\ H_2O$. Oxides of iron 40·6 (metallic iron 28·4), Arsenic acid 39·8, Phosphoric acid 2·5, Water 17·1.

Pyr. Like scorodite, but gives reactions for phosphoric acid similar to vivianite.

Loc. Generally associates with, and often invests, arsenopyrite and copper pyrites. Biggenden, Q., with bismite and native gold.—Emmaville, Bungonia, N.S.W., with arsenopyrite and galena.—Beehive Reef, Maldon; Port Phillip Mine, Clunes; St. Arnaud, Crooked River, Mt. Prospect, Broadford; Merton Creek, Doon, Vic.—With arsenopyrite on quartz, Teetulpa, S.A.—Waterhouse Gold-field, Tas.

207. MELANTERITE (*Copperas, Iron Vitriol*). Monoclinic; prisms with modified lateral edges. Crystals not common. Usually in finely fibrous aggregates, stalactitic, concretionary, encrusting, massive, powdery. Cleavage prismatic and basal perfect.

H 2. G 1·8. Lustre vitreous. Colour green, greenish white. On exposure oxidizes and is covered with a coating of yellow copiapite. Streak white. Translucent. Fracture conchoidal. Brittle. Taste metallic, sweetish astringent.

Comp. Hydrous sulphate of iron, $FeSO + 7\ H_2O$. Oxide of iron 25·9 (metallic iron 20·1), Sulphuric acid 28·8, Water 45·3. Sometimes mixed with copper vitriol, and then is of a deeper greenish-blue colour.

Pyr. BB swells up, changes colour to brown and red, and fuses at 1 to a black magnetic globule. In the closed tube yields water. Fused with soda on charcoal yields an hepar. Completely soluble in water; in the aqueous solution chloride of barium throws down a heavy white precipitate of sulphate of barium.

Loc. Copperas results chiefly from the decomposition of pyrite (*q. v.*), marcasite, and copper pyrites; it occurs efflorescent in dry situations, but passes mostly into the mine water. Gilberton district, Q.—Lachlan; in quartz veins north of Albury, N.S.W.—Beehive Reef, Maldon; Lal Lal; Parker's Mine, Gordon, Vic.—Waukaringa, Teetulpa, S.A. —Zeehan, Waratah, Beaconsfield, Tas.—Geraldine, W.A.

208. COPIAPITE (*Misy*). Hexagonal; six-sided and rhombic scales, granular, encrusting, pulverulent.

H 1·5. G 2·1. Lustre pearly to dull. Colour and streak sulphur yellow, inclined to ochre yellow. Translucent to opaque.

Comp. Hydrated basic sulphate of iron, $Fe_4S_5O_{21} + 18\ H_2O$. Peroxide of iron 34·2 (metallic iron 23·4), Sulphuric acid 42·7, Water 23·1; often with some lime, magnesia, and alumina.

Pyr. Insoluble in water, otherwise like melanterite.

Loc. Results from the peroxidation and hydration of pyrite, marcasite, etc., in most of the localities mentioned under melanterite.

209. WOLFRAMITE (*Wolfram*). Monoclinic; tabular prisms. Cleavage clinodiagonal perfect, orthodiagonal imperfect. Usually in cleavage prisms, laminar, columnar, sometimes divergent, granular, massive.

H 5. G 7·1—7·5. Lustre sub-metallic. Colour brownish or greyish black. Streak red brown to brownish black. Sub-translucent to opaque. Sometimes feebly magnetic.

Comp. Tungstate of iron and manganese, $FeWO_4 + MnWO_4$, the ratio of iron to manganese ranging from 4 : 1 to 1 : 4. Iron oxide 5 to 20, Manganese oxide 3·5 to 20, Tungstic acid 74 to 76, often with a small proportion of lime and titanic acid.

Pyr. BB fuses at 3 to a crystalline, magnetic globule. With soda on charcoal forms blue manganate of soda. With borax gives the reaction of iron and manganese (see general observations under "Iron Group"). Decomposed by aqua regia with separation of yellow granular tungstic acid. Boiled down with P_2O_5 gives a blue syrup (WO_3) which is changed to violet on the addition of nitric acid (MnO).

Loc. Wolfram occurs in quartz, usually associated with cassiterite, molybdenite, bismuth, scheelite, schorl, gold. On decomposition yields *tungstite* (tungstic ochre, WO_3), a yellow pulverulent substance often deposited on the surface and joints of wolfram. Stanthorpe, Tinaroo, Muldwa, Mackay; Noble Island, off Cape Melville, Q. - Glen Innes, Elsmore, Newstead, Emmaville, Kingsgate; Waukeroo, north of Broken Hill, N.S.W. Superb Reef, Linton; with bismuth, gold, molybdenite, and tourmaline. Maldon, Upper Yarra, Beechworth, Omeo, Vic.—Onkaparinga, Port Victor, S.A.—Blue Tier, Ringarooma, Ben Lomond, Mt. Claude, Upper Leven River, Tas.—Lake Wakatipu, Otago, N.Z.

COBALT GROUP.

The minerals of this group yield after thorough roasting on charcoal a metallic residue which is more or less magnetic. Dissolved in borax or microcosmic salt they colour the glass smalt blue in both flames; the presence of other metallic oxides interferes with this coloration. Minerals containing manganese, iron, cobalt, nickel, and copper should be fused with metallic arsenic or potassium arsenate in the closed tube, and then treated with borax glass on charcoal. By using successively fresh portions of borax the bead appears first yellowish green (iron), then blue (cobalt), next brown and grey (nickel), and finally opaque red (copper). They are soluble in nitric acid, imparting a rose-red colour to the solution.

Native, uncombined cobalt is unknown. Metallic cobalt, artificially produced, is silvery white to steel grey, has a strong metallic lustre, and is susceptible of a high polish. It is uncertain whether it possesses the property of ductility to any marked degree, as manufacturers have not yet succeeded in producing plate or wire of cobalt. In its behaviour towards electric and magnetic currents it resembles iron, and as it does not oxidize it is eminently suitable as a substitute for soft iron in electro-magnetic instruments.

210. SMALTITE. Isometric; cube, octahedron, tetrahedron, and their combinations. Also massive and reticulated. Cleavage octahedral perfect.

H 6. G 6·4—7·2. Lustre metallic. Colour tin white to steel grey; on exposure becomes dark grey and iridescent. Streak greyish black. Fracture uneven. Brittle.

Comp. Arsenide of cobalt, iron, and nickel, $(Co, Fe, Ni)As_2$. Cobalt 9·4, Iron 9, Nickel 9·5, Arsenic 72·1, but the ratio of the three metals varies considerably. Some kinds have Cobalt 23, Nickel 2, Iron 2—12, while *Chloanthite*, which is merely a niccoliferous smaltite, contains Cobalt 3, Nickel 21, Iron 3. Most varieties also contain copper and sulphur.

Pyr. F 1. In the open tube and on charcoal gives arsenical vapours. With borax on charcoal reacts for iron, cobalt, and nickel.

Loc. Occurs in mineral veins with other ores of cobalt, nickel, and copper. Nichol's Nob and Mt. Ogilvie, Mt. Lyndhurst district, S.A.

211. COBALTITE. Isometric; compound forms of cube and octahedron. Cubic faces striated. Also granular and compact. Cleavage cubic perfect.

H 5·5. G 6—6·3. Lustre metallic. Colour silver white with a pink tinge, steel grey with a purplish tinge, iron black. Streak greyish black. Fracture uneven. Brittle.

Comp. Sulpharsenide of cobalt $Co(S, As)_2$, but more commonly $(Co, Fe)S_2 + (Co, Fe)As_2$. Cobalt 9—34, Iron 3—28, Sulphur 19·3, Arsenic 45·2.

Pyr. F 1. In the open tube and on charcoal evolves sulphurous and arsenical vapours. The blue borax glass in OF has a slight greenish tinge.

Loc. Found in veins in crystalline schist. On decomposition yields erythrite. Occurs in the Australian Broken Hill Mine, Barrier Range, in immediate contact with dyscrasite and tetrahedrite.—Mt. Ogilvie, S.A., with smaltite and erythrite.—Penguin, Tas., with argentiferous galena.

212. ERYTHRITE (*Cobalt Bloom*). Monoclinic; polyhedral prism surmounted by truncated clinodomes. Prismal faces longitudinally striated. Also botryoidal, reniform, columnar, stellate, earthy. Cleavage clinodiagonal perfect.

H 2. G 2·9. Lustre of cleavage planes pearly, otherwise vitreous to dull. Colour peach-blossom red. Streak pink. Transparent, translucent, opaque. Cleavage plates flexible. Sectile.

Comp. Hydrous arsenate of cobalt, $CO_3As_2O_8 + 8\ H_2O$. Oxide of cobalt 37·6 (metallic cobalt 29·6), Arsenic acid 38·4, Water 24; usually with some ferric oxide.

Pyr. BB fuses at 2 to a grey metallic globule. In the closed tube yields water, and its colour changes from pink to indigo blue. On charcoal gives arsenical fumes. Colours the borax bead pure smalt blue.

Loc. Erythrite is chiefly derived from the decomposition of cobaltite or cobaltiferous arsenopyrite. Mt. Biggenden, Q., with scorodite, bismite, and gold.—Broken Hill lode, N.S.W., with cobaltite.—Walhalla, Vic., with asbolite.—Mt. Ogilvie; Blinman, S.A., with other cobalt ores.—Penguin, Hampshire Hills, Tas.

NICKEL GROUP.

The minerals of this group yield after roasting a more or less magnetic mass. The borax glass in the oxidizing flame is reddish violet while hot, and red brown when cold; in the reducing flame it is colourless while hot, and on cooling becomes grey, turbid to opaque through finely disseminated metallic nickel. In the presence of iron the oxidized borax bead is brown red hot and brown cold. The reduced bead after separation of nickel is bottle green. In the presence of cobalt the colours are violet blue and purplish brown; after the reduction of the nickel smalt blue. The microcosmic salt glass in the oxidizing flame is red brown hot, yellow to orange cold; in the reducing flame, with the addition of chloride of tin, grey turbid to opaque (see also under "Cobalt Group"). With nitric acid they give green solutions which on the addition of an excess of ammonia become sapphire blue. Metallic nickel does not occur in nature except in meteorites (see Native Iron).

213. PENTLANDITE (*Nickel Pyrites*). Isometric; crystals indistinct. Octahedral cleavage. Usually granular massive.

H 4. G 4·6. Lustre metallic. Colour bronze yellow. Streak brown.

Comp. Sulphide of nickel and iron, $2\,FeS + NiS$. Nickel 22, Iron 41·9, Sulphur 36·1. Frequently contains cobalt and copper. A decrease in the amount of nickel brings about a passage into niccoliferous pyrrhotite.

Pyr. BB fuses at 1 to a magnetic globule. In the open tube yields sulphur. After roasting the powder gives with the fluxes reactions for nickel and iron.

Loc. Occurs with pyrrhotite and copper pyrites in serpentine and hornblendic rocks. Pinnacles, Barrier Range; near Elsmore, N.S.W.—Flinders Range; Port Lincoln district, S.A.—Heazlewood, Tas.—New Caledonia.

Econ. Pentlandite and pyrrhotite constitute next to garnierite the chief source of the nickel of commerce. The principal mines are at Sudbury, Canada; the Appalachians, U.S.A.; and Scandinavia.

214. NICCOLITE (*Copper Nickel*). Hexagonal; truncated pyramids. Crystals indistinct and rare; mostly reticulated, dendritic, massive.

H 5. G 7·5. Lustre metallic. Colour copper red; tarnishing greyish black. Streak brownish black. Opaque. Fracture uneven. Brittle.

Comp. Arsenide of nickel, $NiAs$. Nickel 44·1, Arsenic 55·9; frequently with some cobalt, iron, bismuth, antimony, sulphur.

Pyr. BB fuses at 1 to a black metallic globule. In the open tube and on charcoal evolves arsenical fumes. With borax on charcoal gives reactions, successively, of iron, nickel, and cobalt.

Loc. Occurs in veins with other ores of nickel and copper. Bathurst; Weare's Creek, Peel River, N.S.W.—Mt. Ogilvie, S.A., with *gerstorffite* ($NiS_2 + NiAs_2$) and smaltite.—Penguin, Tas.—New Caledonia.

215. ULLMANNITE (*Nickel Antimonite*). Isometric; cube octahedral. Also granular massive. Cleavage cubic perfect.

H 5. G 6·2—6·5. Lustre metallic. Colour light steel grey. Streak greyish black. Brittle.

Comp. Sulphantimonide of nickel, $NiSb_2 + NiS_2$. Nickel 27·7, Antimony 57·2, Sulphur 15·1. Part of the nickel usually replaced by iron and cobalt, and part of the antimony by arsenic.

Pyr. F 2—3. After thorough roasting on charcoal leaves a feebly magnetic globule which, treated with borax, reacts for nickel. In the open tube and on charcoal gives dense antimony fumes, sulphurous, and frequently also arsenical, vapours.

Loc. Occurs disseminated in siderite in a brecciated vein at Gill's Bluff, Mt. Lyndhurst, Flinders Range, S.A.

Var. Willyamite. G 6·87. *Comp.* Ni 13·5, Co 13·8, Sb 56·8, S 15·9. Occurs with dyscrasite in calcite and siderite at a depth of 150 feet in the Australian Broken Hill Mine, Barrier Range, N.S.W.

216. ZARATITE. Amorphous; flat botryoidal, encrusting, massive, earthy.

H 3. G 2·6. Lustre vitreous to dull. Colour emerald green. Streak paler than the colour. Translucent. Brittle.

Comp. Hydrous carbonate of nickel, $NiCo_3 + H_4Ni_2O_4$. Oxide of nickel 59·4 (metallic nickel 46·7), Carbon dioxide 11·7, Water 28·9. Often rendered impure by admixture of magnesia, ferric oxide, clayey and siliceous matter.

Pyr. BB infusible, loses carbonic acid, becomes black and magnetic. With borax gives nickel reaction. Soluble with effervescence in HCl.

[illegible]

[illegible]

Comp. Hydrous [illegible] and magnesia, NiO, [illegible] a mix- [illegible] with oxide [illegible] 2—24, Magnesia [illegible] 47 [illegible] Protoxide of iron 1—6. [illegible]

Pyr. BB infusible, darkens. With borax gives nickel reaction. In the closed tube yields water. Decomposed by HCl with separation of gelatinous silica.

Loc. New Caledonia: to the east of Noumea in the belt of serpentine which extends from Borandi northward for eighty miles to Ouailou, and from near the seaboard to an elevation of 3000 feet. It occurs in irregular bunches in the serpentine, partly also in brecciated veins, usually associated with chromite. Much of the ore is mixed with ferruginous clay and has a purplish-brown colour ("Chocolate ore"). The principal mines are the Boa Kaine at Kanala, and the Bel Aire at Ouailou.

218. MORENOSITE (*Nickel Vitriol*). Monoclinic (?). Acicular, fibrous, efflorescent.

H 2. G 2. Lustre vitreous. Colour greenish white, apple green, bluish green. Streak paler than the colour. Brittle. Taste astringent, metallic.

Comp. Hydrous sulphate of nickel, $NiSO_4 + 7\ H_2O$. Oxide of nickel 26·7 (metallic nickel 21), Sulphuric acid

28·5, Water 44·8. Frequently contains sulphate of iron, copper and zinc, alum, and arsenic acid.

Pyr. BB swells up; fuses at 1 to a porous brown slag, which with borax gives a nickel reaction. In the closed tube yields water and sulphuric acid, and becomes opaque yellow. Soluble in water.

Loc. Occurs with other nickel ores in dry situations near the surface. Farina, S.A. -- Beaconsfield, Tas.

ARSENIC GROUP.

The minerals of this group give in the open tube and on charcoal fumes of arsenous acid which emit the odour of garlic, and condense to a white sublimate which is easily volatilized, and colours the blowpipe flame faintly blue. In the presence of much sulphur the garlic odour is apt to be masked, and in that case the assay should be fused with soda on charcoal.

219. **NATIVE ARSENIC.** Hexagonal; rhombohedron, modified by basal planes. Usually concretionary, botryoidal, reniform, stalactitic, granular massive. Cleavage basal imperfect.

H 3—4. G 5·9. Lustre on fresh fractures metallic, on exposure becomes dull grey. Colour tin white. Fracture uneven.

Comp. As; generally with small proportions of antimony, bismuth, iron, silver, gold.

Pyr. BB on charcoal volatilizes without fusion, colouring the flame pale blue, and coating the charcoal with white oxide.

Loc. Occurs in mineral veins traversing crystalline schist. Solferino, N.S.W., with arsenopyrite. Mitchell's Creek, with gold and silver. Boorook, auriferous with stibnite. Louisa Creek, Wellington, N.S.W.—Mt. Bischoff, Tas., interlaminated with siderite, and associated with arsenopyrite, fluorite, and sphalerite. Kapanga, Auckland, with calcite. Thames River, N.Z., concretionary with calcite and quartz.

220. REALGAR. Monoclinic; six- and eight-sided prisms. Also granular and compact. Cleavage basal distinct.

H 2. G 3·5. Lustre resinous. Colour and streak orange red. Translucent. Fracture conchoidal.

Comp. Monosulphide of arsenic. AsS. Arsenic 70·1, Sulphur 29·9.

Pyr. In the closed tube fuses at 1, and yields first a yellow sublimate of sulphur, and then a sublimate of sulphide of arsenic, which is dark red brown to black while hot, and orange red when cold. In the open tube gives sulphurous fumes and a white sublimate of arsenous acid. Soluble in KHO.

Loc. Accompanies sulphides and arsenides of silver and other metals. Artificially produced in the roasting of arsenical pyrites. Louisa Creek, N.S.W.—Bethanga, Maldon, Vic.

Realgar decomposes by weathering to orpiment and arsenolite, thus—

$$3\ \mathrm{AsS}\ (\text{Realgar}) = \mathrm{As} + \mathrm{As_2S_3}\ (\text{Orpiment}).$$

$$\mathrm{As_2} + \mathrm{O_3} = \mathrm{As_2O_3}\ (\text{Arsenolite}).$$

221. ORPIMENT. Rhombic (Monoclinic ?); polyhedral prism terminating in brachydomes. Also concretionary, foliated, massive. Cleavage brachydiagonal very perfect.

H 2. G 3·4. Lustre resinous to pearly. Colour bright lemon yellow. Streak sulphur yellow. Translucent. Thin plates somewhat flexible. Nearly sectile.

Comp. Sesquisulphide of arsenic, As_2S_3. Arsenic 61, Sulphur 39.

Pyr. Like realgar.

Loc. Results usually from the oxidation of realgar (*q. v.*). Of rare occurrence in nature. A common furnace product.

222. ARSENOLITE (*White Arsenic*). Isometric; octahedral. Also capillary, botryoidal, encrusting, earthy.

H 1·5. G 3·7. Lustre vitreous to silky. Colour and streak white; the occasional yellow or red tinge is due to the presence of orpiment and realgar. Transparent to nearly opaque. Taste sweetish astringent.

Comp. Arsenous acid, As_2O_3. Arsenic 75·8, Oxygen 24·2.

Pyr. BB completely volatilized. In the closed tube gives a crystalline sublimate. With soda on charcoal emits arsenical fumes. Appreciably affected by cold, more so by boiling water.

Loc. Occurs occasionally with arsenical ores in mineral veins. A common product of sublimation, as takes place during the roasting of arsenical pyrites in reverberatory furnaces.

ANTIMONY GROUP.

Antimony compounds yield in the open tube and on charcoal dense white fumes of teroxide of antimony, which condenses at a considerable distance from the assay, and is easily, though less readily than arsenous acid, dislodged by the point of the blowpipe flame. The latter is coloured pale greenish blue. After further heating the antimonous oxide is converted into pentoxide, which is yellowish white while hot and pure white when cold. It sublimes on the nether side of the open tube, and is non-volatile. Dilute nitric acid changes metallic antimony to teroxide, concentrated nitric acid to pentoxide. Both oxides are almost insoluble in nitric, but readily dissolve in hydrochloric acid.

223. **NATIVE ANTIMONY.** Hexagonal; rhombohedron with basal planes. Usually granular massive, laminar; rarely concretionary. Cleavage basal highly perfect.

H 3. G 6·6. Lustre metallic. Colour tin white. Non-ductile. Brittle.

Comp. Sb, usually with 1 or 2 per cent. of arsenic, silver, or iron.

Pyr. BB fuses at 1, takes fire, and surrounds itself with a white coating of oxide. Readily crystallizes after fusion under a cover of flux.

Loc. Native antimony is of rare occurrence. Occurs in the Burnett district, Q.—Lucknow, N.S.W., with gold and silver; Gara, near Armidale, with argentiferous stibnite.—Reported from Ketchowla, S.A.—With galena in quartz, Hay's Mine, Castray River, Tas.—Large masses have been found at Borneo.

224. Stibnite (*Antimonite, Grey Antimony Ore*). Rhombic; four, six, and eight-sided prisms with pyramidal terminations. Acicular crystals aggregated in parallel or divergent bundles. Also fibrous, columnar, and granular. Cleavage brachydiagonal very perfect.

H 2. G 4·5. Lustre metallic. Colour and streak light lead grey. On exposure darkens and sometimes acquires an iridescent tarnish. Fracture minutely conchoidal. Sectile.

Comp. Sulphide of antimony, Sb_2S_3. Antimony 71·8, Sulphur 28·2; frequently with some lead, iron, copper, silver, gold.

Pyr. F 1. In the closed tube gives a sublimate which is black while hot and cherry red to brownish red when cold. In the open tube and on charcoal spreads out and yields fumes of antimony teroxide, a non-volatile sublimate of pentoxide, and sulphurous vapours. With soda on charcoal forms an hepar and metallic antimony. The powder treated with KHO turns ochre yellow and is mostly dissolved.

Loc. Occurs in quartz veins usually with pyrite, sphalerite, and galena. Sometimes in beds of siderite. With gold at Northcote, Gympie, Hodgkinson, and the Burnett district. With galena at Neerdie near Ravenswood, and Tinaroo, Q.—Abundantly at Hillgrove, N.S.W., with *berthierite* ($FeS + Sb_2S_3$) in quartz gangue; yields up to 4 oz. of gold to the ton. Auriferous at Temora, Bathurst. Argentiferous at Fairfield, Peelwood, Bendemeer, Uralla, Bingera, Macleay River, generally in brecciated quartz veins traversing

Devonian strata. With cassiterite, wolfram and molybdenite on most of the tin-fields of New England, N.S.W.—Templestowe, Wandong near Kilmore, Whroo, and Costerfield in quartz veins in Upper Silurian slate and sandstone. The Costerfield stibnite has afforded as much as 80 oz. of silver and 9 oz. of gold to the ton. Blackwood, Bacchus Marsh, Maryborough, Dunolly, in Lower Silurian. In auriferous quartz reefs at Ballarat, Elaine, Steiglitz. In rolled pieces accompanying alluvial gold at Daylesford, and Ballarat, Vic.—Mount Fitton, Kanmantoo, S.A.—Mt. Bischoff, Lefroy, Mt. Claude, Tas.—Auriferous at Mallina, east of Roebourne, W.A.—Endeavour Inlet, Cook's Strait; Shotover Diggings, Waipori, Waitahuna, Otago; Tararu Creek, Thames gold-field. Argentiferous at Boatman's, Murray Creek, Reefton, Mangahua, Greymouth, Collingwood, in the province of Nelson, N.Z. At Collingwood the ore has sometimes yielded at the rate of 180 oz. of silver to the ton.

225. CERVANTITE (*Antimony Ochre*). Rhombic; acicular. Commonly massive, encrusting, pulverulent.

H 4·5. G 4. Lustre of crystals resinous to pearly, otherwise dull. Colour ochre yellow, sulphur yellow, yellowish white. Streak paler than the colour.

Comp. Antimonate of teroxide of antimony, $SbO_3 + SbO_5 = SbO_4$. Antimony 79·2, Oxygen 20·8. Usually contains water and ferric oxide, and an admixture of clayey, siliceous, or calcareous matter.

Pyr. Infusible. With soda on charcoal easily reduced.

Loc. Cervantite is a common decomposition product of stibnite, and is found in the gossan of antimony lodes in most of the localities mentioned under stibnite.

BISMUTH GROUP.

The minerals of this group are easily reduced by fusion on charcoal, producing a coating which is dark orange yellow while hot and lemon yellow while cold, and at a further distance from the assay a white fringe of carbonate. To distinguish the sublimate from the one afforded by lead the powdered mineral is mixed with potassium iodide and sulphur, and the mixture fused on charcoal, when the bismuth coating receives a fringe of iodide of bismuth, which has a brilliant scarlet colour. All bismuth minerals are soluble in nitric acid. The concentrated nitric solution poured into water produces a white precipitate of basic nitrate of bismuth, which may be filtered, dried, and tested on charcoal as above.

226. NATIVE BISMUTH. Hexagonal; rhombohedron with basal planes. Usually granular, reticulate, arboriform, foliated. Cleavage basal perfect.

H 2. G 9·8. Lustre metallic. Colour and streak white with a reddish tinge; readily tarnishes on exposure and becomes red brown, black, and iridescent. Sectile, rather brittle.

Comp. Bi, usually with some arsenic, iron, tellurium, silver, gold, sulphur.

Pyr. F 1, completely volatilized. In the open tube fuses without fuming, and is covered by oxide, which is brown hot and yellow cold.

Loc. Native bismuth occurs in veins and impregnations, affecting chiefly amphibole rock and tourmaline schist, often in proximity to stanniferous granite. Mount Biggenden, Q., in amphibolite and magnetite, associated with bismuthinite and native gold. Mt. Shamrock, Narrango, Cloncurry, in auriferous quartz. With tin ore at Coolgarra near Herberton, and Stanthorpe, Q.—Glen Innes, in tin granite. Armidale, Vegetable Creek, Kempsey, Orange, Pye's Creek, Barrier Range, N.S.W.—Superb Reef near Linton, Vic., with wolfram, molybdenite, schorl, and gold. Similarly at Sandy Creek, Maldon. Rolled fragments are occasionally met with in auriferous alluvial at Wombat Creek near Omeo, and Upper Yarra, Vic.—Freeling Heights, Mt.

Ogilvie, Balhannah copper-mine, Eveleen Mine, Northern Territory, S.A.—Mt. Ramsay, Tas., in amphibolite with fluorite and chalcopyrite; Blue Tier in tin granite. Weldborough, Mt. Murchison, Bell Mount, Mt. Reid, Tas.

Econ. The bismuth of commerce, which is mainly obtained from bismuthinite, is rarely free from arsenic, iron, and silver. The specific gravity of bismuth at melting-point (526° F.) is 10·06; at 32° F. it is 9·787, that is to say, it expands on solidifying (like ice, but unlike other metals); hence its suitableness as type metal, which should run closely into the fine lines of the mould during cooling. Bismuth has the property of lowering the melting-point of most metals with which it is alloyed. Thus an alloy composed of two parts of bismuth (F = 526°), one part of lead (F = 617°), and one part of tin (F = 442°), forms a solder which fuses at a temperature of 201° F.

227. BISMUTHINITE (*Bismuth Glance*). Rhombic; acicular or bladed crystals. Also fibrous or massive. Cleavage basal and brachydiagonal perfect, macrodiagonal imperfect.

H 2. G 6·4—6·6. Lustre metallic. Colour and streak lead grey. On exposure becomes yellowish, sometimes iridescent. Brittle, inclined to sectile.

Comp. Sulphide of bismuth, Bi_2S_3. Bismuth 81·25, Sulphur 18·75; usually with small proportions of iron, tellurium, copper, gold, silver.

Pyr. F 1. In the closed tube yields sulphurous vapours. On charcoal with soda gives an hepar and metallic bismuth. Other reactions are those characteristic of the group (see above).

Loc. Occurs disseminated in quartz, granite, amphibole rock. Biggenden, Q., often in masses which contain a nucleus of native bismuth. Mt. Shamrock, Q.—Kingsgate, Glen Innes, Armidale, N.S.W.—Superb Reef, Linton, with native bismuth, wolfram, schorl, and gold in quartz. With galena, wolfram, and gold in porphyritic granite at Omeo, Vic.—Balhannah, Mt. Freeling, S.A.—Mt. Ramsay, Heemskirk, Mt. Murchison, Bell Mount, Tas.

228. TETRADYMITE (*Telluric Bismuth*). Hexagonal; rhombohedral, tabular. Also granular, foliated, massive. Cleavage basal very perfect.

H 1·5. G 7·2—7·9. Lustre metallic, splendent. Colour light steel grey. Streak greyish black, shining. In thin laminæ flexible. Sectile. Soils the fingers.

Comp. Telluride of bismuth or sulphotelluride of bismuth, Bi_2Te_3 or Bi_2Te_2S. Bismuth 50—61, Tellurium 34—50, Sulphur 0—5. Usually contains iron, copper, gold.

Pyr. BB on charcoal fuses at 1 to a brittle silver-white globule, which in the continued blast is wholly volatilized, and produces a white coating which colours the flame greenish blue (tellurium), afterwards a yellow coating (bismuth). In the open tube yields a greyish-white sublimate which BB collects into colourless drops. Heated with strong H_2SO_4 colours the latter hyacinth red. When the solution is diluted with water this colour disappears, and a dark grey precipitate of tellurium separates.

Loc. Occurs in veins usually in association with pyrite, chalcopyrite, and gold. Mt. Shamrock, Q., with other bismuth ores and crystallized native gold.—Norongo near Captain's Flat, N.S.W., with pyrite and gold in a gangue of earthy limonite. Also reported from Kingsgate near Glen Innes, N.S.W.

229. BISMITE (*Bismuth Ochre*). Artificial crystals rhombic. In natural condition amorphous, massive, foliated, earthy.

H 1—1·5. G 4·3—4·4. Lustre adamantine to dull. Colour pale ochre yellow, greenish yellow, greenish grey. Fracture conchoidal to earthy.

Comp. Teroxide of bismuth, BiO_3. Bismuth 89·6, Oxygen 10·4; usually with some carbonate of bismuth, water, oxide of iron, and clayey matter.

Pyr. F 2. On charcoal reduced. Gives ordinary bismuth reactions. In the closed tube usually yields a little water.

Loc. Occurs generally with bismuthinite. Mt. Biggenden, Mt. Shamrock, Q.—Glen Innes, N.S.W.—Teetulpa and Forest Range, S.A.—Mt. Murchison, Tas.

230. BISMUTITE. Amorphous; pseudomorphous after bismuthinite; also massive, earthy, and in rolled pebbles.

H 4. G 6·9—7·3. Lustre vitreous to dull. Colour and streak yellowish white, greyish, reddish, greenish white. Sub-translucent to opaque. Brittle.

Comp. Hydrous carbonate of bismuth, $Bi_6CO_{11} + H_2O$. Oxide of bismuth 90·1 (metallic bismuth 81), Carbon dioxide 6·4, Water 3·5. Frequently with some oxide of bismuth, oxide of iron, sulphuric acid, and clayey matter, the impurities not rarely amounting to 10 per cent. Some varieties pass into bismite.

Pyr. F 1; decrepitates. On charcoal reduced. In the closed tube yields water. Soluble with effervescence in acids.

Loc. Results from the alteration of native bismuth and bismuthinite. Frequently harbours native gold. It occurs in the gossan of lodes in most of the localities quoted under bismuthinite, and in rolled pebbles in gold- and tin-drifts. Broughton near Charters Towers, Biggenden, Cloncurry, Q.—Tingha, Tenterfield; in tin-drift in many parts of New England, N.S.W.—Superb Reef, Linton. In alluvial Upper Yarra, Upper Murray; Spring Creek, Omeo; Maldon, Kingower.—In the gossan of auriferous quartz veins at Forest Range, east of Adelaide; Teetulpa, Woodside. In copper lodes, Balhannah, Stanley, Blinman. In alluvial, Forest River, Morialta, S.A.—Abundant in the tin-drift near Bell Mount, Tas.

MANGANESE GROUP.

All the minerals of this group, except rhodonite, are infusible before the blowpipe. They impart a violet or amethystine red colour to the borax and microcosmic salt beads in the oxidizing flame, leaving the glass colourless in the reducing flame. Fused with an excess of soda they produce a sea-green compound of manganate of soda. Metallic manganese does not exist in nature.

231. BRAUNITE. Tetragonal; octahedra, often in macles made up of three individuals. Also massive.

H 6. G 4·8. Lustre sub-metallic. Colour and streak black, brownish black. Fracture uneven. Brittle.

Comp. Protoperoxide of manganese, $MnO, MnO_2 = Mn_2O_3$, commonly with silicate of manganese, and hence more nearly $4 Mn_2O_3 + MnSiO_3$. Protoxide of manganese 83·7, Oxygen 8·4, Silica 7·9. Frequently contains also baryta, lime, iron, water.

Pyr. Infusible. Decomposed by HCl with separation of silica and evolution of chlorine.

Loc. Occurs in the upper parts of metalliferous veins, but is never abundant. Port Macquarie, Gundagai, Rylestone, Wellington, Caloola, N.S.W.—Thompson River, Gippsland, Vic.—Malvern Hills, Canterbury, N.Z.

232. PYROLUSITE. Rhombic; prismatic, acicular. Columnar, parallel, and divergent. Also concretionary, granular massive, pulverulent. Soils the fingers.

H 2. G 4·8. Lustre metallic to sub-metallic. Colour and streak iron grey to bluish black. Opaque. Brittle.

Comp. Dioxide of manganese, MnO_2. Manganese 63·3, Oxygen 36·7. Often with some baryta, silica, and water.

Pyr. BB infusible, but loses oxygen. Soluble in HCl with liberation of chlorine, thus—

$$MnO_2 + 4\,HCl = MnCl_4 + 2\,H_2O$$
$$MnCl_4 = MnCl_2 + Cl_2,$$

the manganic chloride being decomposed into manganous chloride and free chlorine.

Loc. Occurs in beds and veins; sometimes forms the cementing medium of quartz conglomerate. Gladstone, Leyburn near Warwick, Mt. Morgan, Mt. Shamrock, Mt.

Biggenden, Q.—Newcastle, Gulgong, Tamworth, Walcha, Stony Batta, Bendemeer, Bungonia, Caloola, Bathurst, N.S.W.—Yea, Stawell, Ararat, Percydale, Moe, Vic.—Mt. Lyndhurst, Gordon, Orroroo, Herds Hill near Teetulpa, S.A.—Zeehan, Dundas, Meredith Range, Mt. Claude, Penguin, Tas.—Bay of Islands, N.Z.—New Caledonia.

233. MANGANITE. Rhombic; polyhedral prisms, surmounted by domes or octahedra. Prismal faces vertically striated. Basal planes absent. Crystals generally in bundles. Also columnar and stalactitic. Cleavage brachydiagonal highly perfect; prismatic perfect.

H 4. G 4·3. Lustre sub-metallic. Colour iron grey to black. Streak reddish brown to black. Opaque to subtranslucent. Fracture uneven.

Comp. Hydrous sesquioxide of manganese, $H_2(Mn_2)O_4$. Manganese 62·5, Oxygen 27·3, Water 10·2.

Pyr. Infusible. Yields water in the closed tube.

Loc. Not a common species. Rockley, N.S.W.—In opaline quartz, Tasmania.

234. PSILOMELANE. Amorphous, botryoidal, reniform, stalactitic, massive, dendritic.

H 5—6. G 3·7—4·7. Lustre sub-metallic to dull. Colour bluish black to iron black. Streak brownish black, shining. Opaque.

Comp. Hydrous protoperoxide of manganese, $H_2MnO_4 + H_2O$. Manganese 45·5, Oxygen 39·6, Water 14·9. Variable; usually contains oxide of iron, baryta, lime, magnesia, etc.

Pyr. Like manganite. In the hydrochloric solution H_2SO_4 frequently gives a precipitate of sulphate of barium.

Loc. This, the commonest of the manganese ores, occurs in beds and in the gossan of mineral veins. It is frequently accompanied by, and its mode of occurrence is similar to that of, limonite. Gregory River near the confluence of Horse Creek, Toowoomba, Gladstone, Beenleigh, Q.—Broken Hill Lode, Barrier Range, often coated with stilpnosiderite, smithsonite, and invested by calcite and cerargyrite. King's Creek, Jocelyn, Nymagee, N.S.W.—In the upper parts of auriferous quartz veins, Bendigo, Castlemaine, Ballarat. Forms the cementing medium of auriferous quartz-pebble conglomerate of older pliocene age at Maryborough, Linton, Haddon, Ararat, Taradale, not rarely coating the grains and nuggets of gold in the drift and cement. In such cases the psilomelane contains usually a large proportion of oxide of iron, constituting the so-called "ferro-manganese" ore. In veins and cracks in mesozoic sandstone at the Wannon River, Cape Otway district, and South Gippsland, Vic.—Gordon, Orroroo, Willochra, Eurelia, S.A.—In the gossan of silver-lead veins in Western Tasmania.—Russell, Bay of Islands, Whangarei, Waiheke Island, Waipu, island of Kawau, N.Z.—Abundant in the nickel district of New Caledonia.

235. WAD. Amorphous; earthy, reniform, compact.

H 0·5—2. G 3—4. Lustre dull. Colour bluish, brownish black, pure black. Streak black, sometimes shining.

Comp. Hydrous oxides of manganese, MnO_2, Mn_2O, H_2O; usually with iron, cobalt, copper, baryta, silica, and clayey matter in variable proportions. The variety *Asbolite* contains from 2 to 30 per cent. of oxide of cobalt.

Pyr. Like psilomelane, but different varieties give more or less distinct reactions for iron, cobalt, copper, etc.

Loc. Common in many of the localities mentioned under psilomelane. Asbolite occurs at Kilkivan, Cloncurry; Horse Creek, Gregory River; Mt. Biggenden, Q.—Mudgee, Hill End, Fairy Meadows, Bathurst, Orange, Tamworth. In the Hawkesbury sandstone, Blue Mountains; Broken Hill, Barrier Range, N.S.W.—Woods Point, Walhalla, Merton, Ararat, Vic.—Teetulpa, Ediacara, Mt. Lyndhurst; Willowie Forest near Melrose, S.A.—In diorite and serpentine country, Whyte River, Magnet Range, Dundas. Penguin River, Upper Leven, Castray, Tas.—Kanala, New Caledonia.

236. Rhodochrosite (*Diallogite*). Hexagonal; rhombohedron with replaced solid angles; scalenohedron. Also botryoidal, encrusting, granular massive. Cleavage rhombohedral perfect.

H 4. G 3·5. Lustre vitreous to resinous. Colour rose red, purple, brownish red. Weathered specimens become red brown and opaque. Streak uncoloured. Fresh specimens translucent. Fracture uneven. Somewhat brittle.

Comp. Carbonate of manganese, $MnCO_3$. Protoxide of manganese 61·4, Carbon dioxide 38·6. Part of the manganese often replaced by iron, lime, magnesia, and sometimes cobalt.

Pyr. BB infusible; decrepitates, changes colour to brown and black. Soluble with effervescence in hot HCl.

Loc. The separation of carbonate of manganese, like carbonate of iron, from solutions can only take place with the exclusion of oxygen, and the mineral is accordingly but rarely found near the surface. It may be produced in several ways: (1) by the solution of existing carbonate; (2) by the action of carbonated water on manganesian silicates; (3) by the reduction of oxide of manganese in the presence of organic matter which furnishes the carbonic acid. It is readily altered to manganite, and this again successively to pyrolusite, psilomelane, and finally to wad. Undoubtedly, however, pyrolusite is sometimes derived from psilomelane. Rhodochrosite occurs in metalliferous veins generally associated with other manganese ores. Rockley, N.S.W.—Clunes, Vic., in botryoidal crusts on psilomelane.—Barossa, S.A.—Zeehan, Tas., in saddle-shaped rhombohedra investing ferro-manganese ore, deposited in cavities in galena veins.—Dunstan, Otago, N.Z.

237. Rhodonite (*Manganese Spar*). Triclinic; crystals resembling those of augite (Fig. 90). Commonly botryoidal or massive. Cleavage prismatic perfect; cleavage angle 92°.

H 6. G 3·4—3·6. Lustre vitreous. Colour flesh red, pale brownish red. On exposure tarnishes brown to black.

Streak uncoloured. Transparent to opaque. Fracture conchoidal. Tough.

Comp. Silicate of manganese, $MnSiO_3$. Protoxide of manganese 54·1, Silica 45·9. Part of the manganese frequently replaced by iron, lead, zinc, calcium. Sometimes contains carbonic acid, and so passes into rhodochrosite.

Pyr. BB fuses at 3 to a dark-coloured slag which is sometimes magnetic. In the micro. salt bead leaves a skeleton of silica, and colours the glass violet in OF. Only slightly acted upon by HCl, unless it contain much carbonate of manganese.

Loc. Found with other manganese minerals and iron ores in beds and veins. Rockley, Glanmire, Bendemeer, N.S.W. —Elder's Nob, S.A.—Zeehan, Tas.—Dunstan, Otago, N.Z.

TITANIUM GROUP.

The combination of titanium with silica, lime, and iron has been noted in connection with the species titanite and menaccanite (*q. v.*). The three minerals belonging to the group now under notice represent the trimorphous condition of titanic acid. They are infusible. Fused with microcosmic salt in the oxidizing flame the glass is yellowish while hot, and colourless when cold. In the reducing flame it is yellow while hot, and violet when cold. With soda on charcoal they fuse to a yellow glass with a crystalline surface; the glass becomes greyish white when cold. When the soda glass is dissolved in hydrochloric acid, and boiled with a fragment of metallic tin or zinc, the binoxide of titanium is reduced to sesquioxide, which colours the solution purple, and ultimately subsides as a violet precipitate.

238. Rutile. Tetragonal; prisms like those of cassiterite (Fig. 62), often twinned in zig-zag form. Prismal faces usually longitudinally striated. Also octahedral and in twins representing octagonal tables. Frequently acicular. Cleavage

prismatic and diagonal distinct. Sometimes granular compact.

H 6·5. G 4·2. Lustre adamantine, metallic. Colour brown, reddish to blackish brown, more rarely green, yellow, bluish, purple. Streak pale brown. Translucent to opaque. Fracture uneven. Brittle.

Comp. Titanic acid, TiO_2. Titanium 61, Oxygen 39; sometimes with small portions of iron or chromium.

Pyr. As above.

Loc. Occurs in granite, syenite, crystalline schists, sometimes in granular limestone and dolomite, either disseminated through the rock, or embedded in quartz or felspar. It has also been observed finely dispersed in hematite, and it is not improbable that much of what is described as menaccanite is in reality an intimate mixture of hematite and rutile. Also occurs in loose grains and rolled fragments in soils and drifts. Palmer, Herberton, Milton, Q., in granite quartz.—In crystallized quartz, Cope's Creek. In semi-rounded crystals and rolled grains in gem-sand, Bathurst. Mt. Walsh near Uralla, N.S.W.—Acicular crystals with schorl in quartz, Superb Reef, Linton. In gold-drift, Newbury, Blackwood, Upper Yarra, Vic.—Morialta, Watts Gully, Gumeracha, Echunga, Tanunda Creek, S.A.—In quartz at Moorina; in drift Clayton River, Savage River, south-west of Mt. Lyell, Brown's Plains, Tas.—In the copper and gold district of the Grand Diahot River, New Caledonia, rutile occurs in quartz veins traversing mica schist containing glaucophane and garnets.

239. ANATASE (*Octahedrite*). Tetragonal; usually tabular square prism surmounted by acute pyramids, truncated and with replaced polar edges. Often in rolled grains. Cleavage basal and octahedral perfect.

H 6. G 4. Lustre adamantine, metallic. Colour brown, dark blue, black. Streak white. Fracture sub-conchoidal. Brittle.

Comp. and *Pyr.* Like rutile.

Loc. Occurs in quartz and felspar, often together with rutile, in granitic and metamorphic rocks. In sub-angular pieces in the gold-drift of the Cudgegong and Burrandong rivers, N.S.W.—Head of Yarra River, Vic.—Clayton Rivulet, Forth River, southern slope of Mt. Lyell, Brown's Plains, Tas.

240. **Brookite.** Rhombic; modified prism with domes or truncated octahedra. No distinct cleavage. Also in loose grains and rolled pieces.

H 6. G 4—4·2. Lustre adamantine, metallic. Colour chocolate brown, reddish, yellowish. Translucent. Also opaque black with sub-metallic lustre. Streak brownish white to dark grey. Brittle.

Comp. and *Pyr.* Like rutile.

Loc. Occurs in quartz and felspar in granite and foliated schist; also in galena and other metalliferous veins. Mudgee, with diamond and other gem-stones in drift and cement. Burrandong River, N.S.W.—Baw Baw Mountains; at the head of the Yarra River. Mt. Greenock Lead, Talbot in gold-drift. On joints of quartz, Steiglitz, Vic.—Clayton Rivulet, Pieman River, Back Creek near Lefroy, Tas.

URANIUM GROUP.

The minerals of this group afford with borax a glass which in the oxidizing flame is reddish yellow while hot, and colourless or faintly yellow when cold; in the reducing flame the bead is dark green, or, when highly saturated, turbid blackish green. Ferriferous varieties are fused with soda on charcoal in order to reduce the iron oxide; the remaining slag is yellowish brown. This reaction distinguishes uranium from chromium, which, similarly treated, leaves a green slag. Oxide of uranium fused with common glass imparts to it the property of dichroism, viz. yellowish by transmitted light and emerald green by reflected light.

241. Uraninite (*Pitchblende*). Isometric; octahedral. Crystals rare; usually botryoidal, massive, and in grains.

H 5·5. G 6·5—8. Lustre resinous, sub-metallic to dull. Colour of crystals pitch black; of massive varieties brownish, greenish, greyish black. Streak greyish or greenish black, shining. Opaque. Fracture conchoidal.

Comp. Protoperoxide of uranium, UO. 2 UO. Uranium 76, Oxygen 24. Generally contains FeO, MnO, CaO, MgO, Pb, Cu, Zn, Bi, As, Al_2O_3, SiO_2, CO_2, S, H_2O, the impurities amounting in the aggregate to from 4 to 28 per cent.

Pyr. Infusible, or fusible at 6. Non-magnetic. Soluble in HNO_3; in the solution potassium ferro-cyanide throws down a red-brown precipitate. Evaporated with P O yields an emerald-green solution.

Loc. Uraninite occurs sparingly in silver, lead, and tin veins in Cornwall, Saxony, Hungary.

242. Liebigite. Amorphous; encrusting.

H 2. G 6—7. Lustre vitreous to dull. Colour bright apple green. Transparent to opaque.

Comp. Hydrated carbonate of uranium and calcium, $UC_2O_6 + 2\,CaCO_3 + 36\,H_2O$. Protoxide of uranium 37, Lime 16, Carbon dioxide 24, Water 23. Variable.

Pyr. Effervesces in acids. Decomposed by H_2SO_4 with separation of a white precipitate of sulphate of calcium. Otherwise like uraninite.

Loc. Liebigite is a decomposition product of other uranium ores. An impure variety, mixed with some clayey and ochreous matter, and enclosing native gold, occurs at Mt. Ogilvie, S.A.

MOLYBDENUM GROUP.

243. Molybdenite. Triclinic (?). Six-sided plates; macles made up of three individuals, often striated in different directions. Usually foliated, scaly, inclined to granular. Cleavage basal highly perfect.

H 1. G 4·5. Lustre metallic. Colour lead grey. Streak on paper grey, on porcelain greenish. Opaque. Laminæ eminently flexible but not elastic. Sectile. Feels greasy. Soils the fingers.

Comp. Sulphide of molybdenum, MoS_2. Molybdenum 59, Sulphur 41. Frequently contains silver; sometimes encloses native gold.

Pyr. BB infusible; colours the flame pale green. On charcoal, after strong heating in OF gives a coating which is yellowish white while hot, and pure white when cold, and partly crystalline. This sublimate, which is non-volatile, becomes indigo blue when touched for an instant with the tip of the flame (MoO_2); after prolonged heating it acquires a dark copper-red colour and a metallic lustre (MoO_3). The micro. salt bead appears in OF yellowish green while hot, and almost colourless when cold; in the RF dark greyish green while hot, and pure green when cold. With soda on charcoal forms an hepar.

Loc. Occurs chiefly in orthoclastic rocks, *e.g.* granite, syenite, gneiss, mica schist, and in quartz veins traversing these rocks. Sometimes in granular limestone. Usually associated with tin ore, scheelite, apatite, rutile, zircon; sometimes with gold and silver. Found in stanniferous granite in most of the localities mentioned under cassiterite. Head of Pioneer River, Mackay; Chowey Creek, Herberton, Stanthorpe, Q.—Elsmore, Glen Innes, Capertree, Hunter River, Bullin Flat near Goulburn, Bolivia, Jinjellic, Pambula, N.S.W.—Omeo, Crooked River, Buffalo Range, Yackandandah, Yea, Maldon, Superb Reef near Linton, Mt. Beckworth, Mt. Moliagul, Vic.—In cupriferous porphyry, Moonta; Franklin Harbour, S.A.—Flinders Island, Blue Tier, Mt. Heemskirk, Whyte River, Emu River, Tas.—Darling Range, Guildford, W.A.

244. Molybdite (*Molybdenum Ochre*). Rhombic, capillary, radiating fibrous, pulverulent.

H 1·5. G 4·5. Lustre silky to dull. Colour light ochre yellow to sulphur yellow.

Comp. Molybdic acid, MoO_3. Molybdenum 65·7, Oxygen 34·3.

Pyr. F 1. Heated on charcoal emits vapours which condense to a yellowish-white crystalline coating, which gives the reactions described under molybdenite. Soluble in HCl. A fragment of metallic tin placed in the hydrochloric solution imparts to the latter a blue colour.

Loc. Molybdite results from the decomposition of molybdenite, with which it occurs associated in most of the localities mentioned under that mineral. Characteristic at Pambula, N.S.W., in yellow, silky, radiating tufts of capillary crystals, together with molybdenite in aplite.

INDEX TO MINERALS